ABSTRACT

SENANAYAKE, MUDITHA MANJULA. MIXED MASS PRODUCTION AND MASS CUSTOMIZATION: BEST PRACTICES FOR APPAREL. (Under the direction of Dr. Trevor J. Little and Dr. Russell E. King)

Mass-Customization (MC) is growing in importance. The Mass Production (MP) practices and supply strategies lead to excessive markdowns, unsold SKU's and a high rate of consumer dissatisfaction. Industry information for cost economics of MC depicts the comparative advantage of MC business model for both the manufacturer and the retailer compared to the long practiced MP. Most importantly, the consumers gain by obtaining products that satisfy the needs and expectations. This business strategy that optimizes consumer input into product design and selection coupled with responsive manufacturing and the elimination of markdowns offers a new paradigm for a wide market in apparel. When apparel companies that currently practice MP and demanding to adopt MC, it is essential to identify a suitable manufacturing strategy.

The literature review is a comprehensive look at production systems, benchmarking, supporting technologies and MC. The published literature does not address research conducted on mixed MP and MC in apparel manufacturing. However, the survey conducted a part of this research demonstrates that several companies are working on manufacturing system solutions to practice mixed MP and MC. Based on the raised research questions and the research proposal, seven research hypotheses were introduced. These hypotheses proposed number of original concepts for the current research. Mixed manufacturing of MP and MC in the same production line and the identified 5 Points of Customization are emphasized. The technology readiness for apparel mass customization is questioned. With the increasing demand for customized

apparel, whether MP may become custom production with dedicated production lines is addressed.

To investigate the quantitative issues of mixing MP and MC in different production systems, PBS and Kanban manufacturing system modeling and simulation were used. To evaluate the results from the simulation and to further address the broader aspects of the proposed strategy, an industry survey, a case study and personal communications were used. Two strategies that implement the mixed manufacturing of MP and MC were used considering the MC continuum. The Industry Survey Instrument collected information to benchmark current industry practices of MC apparel business models. Personal Communication with industry experts and consultants who are involved in MC of apparel and a Case Study Analysis of a current MC operation represented the methods used to test the research hypotheses. The overall objective of this research was not only to research the state of the art of methods, approaches, obstacles and challenges for MC but also to analyze the proposed concept of mixed MP, MC apparel manufacturing with its current practice, potential and capabilities.

The research results show that for PBS and Kanban production system mixed MP and MC apparel manufacturing in the same production unit is feasible but limited by the volume of MC style. However, this possibility also depends on the Point of Customization and the Extent of Customization. Order tracking technology requirement is emphasized. Industry practice information indicates that companies practice MP and MC in the same production unit as well as in separate production units. In addition, wide range of industry practice information such as customization leadtimes, technologies used for MC, logistics information pertaining to MC, and costs associated with MC are discussed in detail that can be used as measures for MC.

MIXED MASS PRODUCTION AND MASS CUSTOMIZATION: Best Practices for Apparel

by

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To my parents, Prema and Lionel,

my brother Chandraseeva and

my wife Neetha

in grateful recognition of

their boundless faith, constant support and encouragement.

Mother,.. this is my promise....

BIOGRAPHY

Muditha Manjula Senanayake received his Bachelor of Science (Engineering) degree in textile & clothing technology (First Class Honors) from the University of Moratuwa, Sri Lanka in 1994. Upon graduation he was employed by a leading Sri Lankan apparel company as a project leader for process improvement and subsequently as a manager for the product development, sample making, pattern making, grading, and marker making department. In 1997 he joined the faculty as an assistant lecturer of the Department of Textile & Clothing Technology at the University of Moratuwa, Sri Lanka. During that time he also worked as a consultant to the apparel industry in Sri Lanka. Muditha was actively involved in several professional organizations where he has served as the treasurer of the Textile Institute, Sri Lanka section and as an executive committee member of the Sri Lanka Apparel Institute.

Muditha came to the USA in 1999 to pursue his Masters degree at NC State University. He obtained his Master of Textiles degree in textile management and technology in 2001 and moved into the Doctoral research and course work. His studies in the College of Textiles were mainly supported by a research scholarship from NC State University and a project funded by National Textile Center for which he worked as a Research/Teaching Assistant. In addition, his research was supported by two industry based research projects. Apart from studies, Muditha actively involved in several other associations at NC State University. He has served as the President of the Textile Association of Graduate Students (TAGS) and as the Mayor for E.S.King Village Council, the graduate student family housing at NC State University. He was offered the Associateship and Chartered Membership from The Textile Institute, UK in 2003.

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On a more personal level, there are many whose contributions should be recognized. My devoted wife, Neetha and my family in Sri Lanka have been a constant source of love, encouragement and support. Thank you for always being right beside me physically or in spirit and encouraging me to achieve this goal. Finally, many of my friends shared the pains and happiness with me during this long journey. My special thanks to Yatin Karpe, Narahari Kenkare and Sedef Uncu for all the help, friendship, encouragement and continuous discussion about courses, research and our lives at every step of my stay at the college.

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LIST OF ABBREVIATIONS

AAMA – American Apparel Manufacturers Association

ABC – Activity Based Costing

AC – Alternating Current

AGV – Automated Guided Vehicle

AMT – Advanced Manufacturing Technology

ARN – Apparel Research Network

ASIC – Application Specific Integrated Circuits

ATO – Assemble-to-Order

CAD – Computer Aided Design

CAM – Computer Aided Manufacturing

CIM – Computer Integrated Manufacturing

CNC – Computer Numeric Control

CODP – Customer Order Decoupling Point

COGS – Cost of Goods Sold

CTO – Configure-to-Order

DAMA – Demand Activated Manufacturing Architecture

DC – Direct Current

DC – Distribution Center

DCP – Design Customization Point

DPD – Delayed Product Differentiation

EDI – Electronic Data Interchange

EOQ – Economic Order Quantity

ERP – Enterprise Resource Planning

ETO – Engineer-to-Order

FASLINC – Fabric and Supplier Linkage Council

FBCP – Fabrication Customization Point

FIGARMA – Fully Integrated Garment Manufacture

FMS – Flexible Manufacturing System

FRCP – Feature Customization Point

FTCP – Fit Customization Point

FWG – Flexible Work Groups

GM – Gross Margin

GMROI – Gross Margin Return on Investment

IT – Information Technology

JIAM - Japan International Apparel Machinery (Trade Show)

JIT – Just-in-Time

KSA – Kurt Salmon Associates

LAN – Local Area Network

MARS – Manufacturer Applied Robotic Sewing

MC – Mass-Customization

MITI – Ministry of International Trade and Industry

MP – Mass Production

MRP – Material Requirement Planning

MTO – Make-to-Order

MTS – Make-to-Stock

NC – Numeric Control

OFE – Order Fulfillment Efficiency

PBS – Progressive Bundle System

PLC – Programmable Logic Controller

PPCP – Post Production Customization Point

PROM – Programmable Read Only Memory

QR – Quick Response

RFID – Radio Frequency Identification

SAFLINC – Sundries and Apparel Findings Linkage Council

SAM – Standard Allowed Minutes

SG&A - Service, General and Administrative cost

SKU – Stock Keeping Unit

STO – Sale-to-Order

TALC – Textile Apparel Linkage Council

TBC – Time-Based-Competition

$[TC]^2$ – Textile and Apparel Technology Corporation

TPT – Throughput Time

TQM – Total Quality Management

TSS – Toyota Sewing System

UPS – Unit Production System

VICS – Voluntary Inter-industry Commerce Standards

WAN – Wide Area Network

WIP – Work-in-Process

CHAPTER 1

1 INTRODUCTION

The apparel industry has been practicing a Mass Production (MP) strategy which focuses on low cost production of mass quantities for homogeneous markets influenced by obtaining the economies of scale. The industry is now developing systems that allow the final consumer input into the product design and development process instead of pushing the products to the market expecting consumer purchases. Over time, with the change of the market expectations, the manufacturing interests have changed. The focus now is creating variety and customization through flexibility and quick responsiveness. This requirement to manufacture apparel products based on individual consumer needs have demanded the apparel industry to undergo a fundamental shift from MP to Mass-Customization (MC). 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 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 goods.

Mass-Customization is growing in importance. Technologies have developed and most in place to support mass-customized apparel manufacturing. Academic research for theoretical and managerial aspects of MC is growing with more books written in the subject of MC. More companies are moving into the practice of MC business models.

As experts point out, MC is one of the signals for change for the US apparel industry that will help to have a competitive advantage over the rapidly moving manufacturing base from the United States. As this research proposes, a lucrative business strategy would be the manufacturing of customized products in a MP environment to obtain the cost benefits that have been enjoyed in the MP.

The Literature Review addresses in detail the MP and its technology infrastructure, flexible and responsive manufacturing, cost economics of MC, principles, techniques, technologies and various other aspects of apparel MC.

When apparel companies that practice MP need to incorporate the MC practice into its business models, it is essential to identify a suitable manufacturing strategy. The question is whether the MC products can be manufactured in the MP systems or is it required to have a separate production system for MC. Another research question that can be raised is the extent to which MC product can be manufactured together with MP systems. Based on the raised research questions and the research proposal, seven research hypotheses are developed. The hypotheses address the mixed MP and MC manufacturing, technology readiness, the influence of Points of Customization and Extent of Customization, the linearity of MC continuum, and the importance of order tracking and benchmarking for the success of mixed MP and MC apparel manufacturing.

The research is designed to test the hypotheses using a multiple method approach such as computer simulation, industry survey, case study and personal communication. The research led to understand the requirements for MP and MC apparel manufacturing and specifically focus on identifying whether customized apparel can be manufactured with MP in a mixed manufacturing system.

The reviewed literature is used to develop information models that are used to design the research methods. This information is used to develop models defining the continuum that expresses the extent of customization. The Points of Customization are defined and verified and a scale for customization is explored. To investigate the quantitative issues of mixing MP and MC in different production systems, manufacturing system modeling and simulation are used. Two strategies that implement the mixed manufacturing of MP and MC are proposed considering the MC continuum. The first strategy addresses the integrating of MC styles into the MP manufacturing system while the second strategy addresses the integrating of MP styles into a already established MC manufacturing system. To evaluate the results from the simulation and to further address the broader aspects of the proposed strategy, an industry survey, a case study and personal communications are used. The Industry Survey Instrument is designed to gather information to benchmark current industry practices of MC apparel business models. Personal Communication with industry experts and consultants who are involved in MC of apparel and a Case Study Analysis of a current MC operation represent the other methods used to test the research hypotheses.

CHAPTER 2

2 LITERATURE REVIEW

2.1 MASS PRODUCTION

Up until the 1700's, economic production was based on the notion of "craftsmen" and also called "artisans". Products were crafted by the hands of skilled persons using limited tools. Over time, following the invention of machinery, craft production continued but industry moved into a new way of thinking about manufacturing. Factories transitioned from using the old manufacturing system to the so-called "American System" of manufacture which was focused on reduction of cost using machines. These machines replaced labor. The defining principle of this manufacturing system was the interchangeable parts. Table 2.1 column 2, shows the highlights of the American System. To meet the demands of the increasingly geographically dispersed economy with production for efficiency and low costs, a system known as Mass Production (MP) was developed. The first four characteristics discussed under American System (Table 2.1) became a part of the total principles of MP where the additional principles are shown in the Table 2.1 column 3. The principle of flow defined Mass Production. The Ford motor company obtained the reputation of fully using this flow production strategy in their MP of automobiles. The focus of low costs and prices in the production of mass quantities influenced to obtain the economies of scale in the assembly-line flow (Pine II, 1999). Using the MP strategy companies made efforts to increase output by adding inputs and improving the throughput of the machines and the productivity of the workers so that the same amount of units could be produced with fewer workers. Though the fixed cost and capital/labor ratio was increased the unit cost could be lowered. MP system required standardized products because any changes or custom work will result in bottlenecks in the production process causing higher costs. With the importance of the scale of the standardized nature of products to maintain low costs, MP system was highly dependent on machines, specialization of work and division of labor. This means that workers carry out specialized, smallest work elements over and over again using highly specialized machines under close observation of a supervisor. “The extent of the specialization of machines was heavily influenced by the extent of the specialization of the labor, as the production process was continually broken down, with workers performing smaller and smaller tasks, these tasks became easier to automate” (Pine-II, 1999). In MP, the entire process depends on each repetition in an assembly line running smoothly and, in order to prevent the rise in costs, a strong focus on operation efficiency. To facilitate for the efficiency, buffers are maintained between workstations thus the work-in-process inventory increases. In the MP practice, standardization of taste allows for standardized design, which allows for mechanized MP and thus allows for mass distribution (Lampel & Mintzberg, 1996).

Table 2.1: Characteristics of production systems evolved over time (Pine-II, 1993)

Craft Production	American System	Mass Production
Skilled hands	Interchangeable parts	Interchangeable parts
Limited tools	Specialized machines	Specialized machines
	Focus on the production process	Focus on the production process
	Division of labor	Division of labor
	Reliance on suppliers	Flow
	Worker skills	Focus on low costs/prices
	Flexibility	Economies of scale
	Continues technological improvements	Product standardization
		Degree of specialization
		Focus on operational efficiency
		Hierarchical organization, professional managers
		Vertical integration

According to Pine II (1999), a feed back loop which explains the cycle of new or extended products produced in the MP environment can be presented as shown in the Figure 2.1. The standardized products manufactured are of low cost and consistent quality for homogeneous markets which will result in stable demand allowing long product life cycles thus long product development cycles. When apparel MP is considered, there are deviations to this cycle due to the nature of the apparel product.

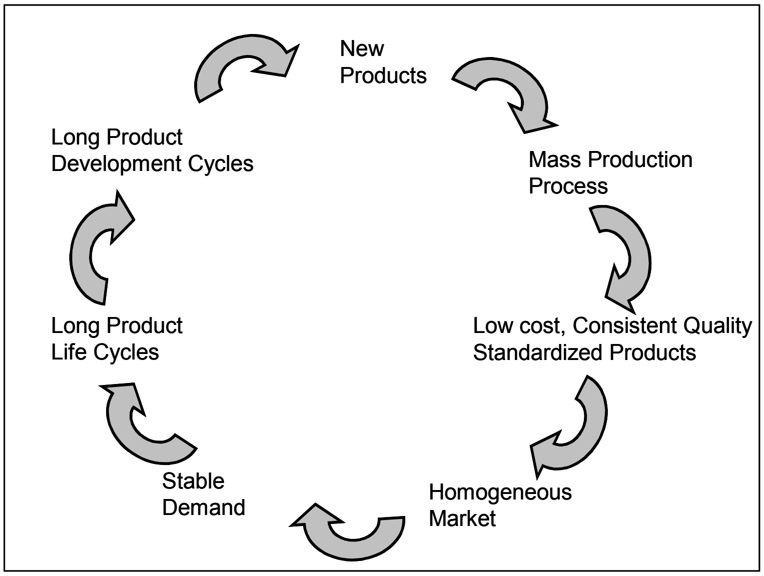

Figure 2.1: The paradigm of MP as a dynamic system of reinforcing factors (Pine-II, 1993)

2.1.1 Mass Production of Apparel

With the general MP apparel business practice, the demand forecast prepared by the marketing department will drive the material requirements planning (MRP) to order the required materials and parts to obtain far enough ahead of time before the production run is scheduled. The line capacity is often determined by the peak demand. Machines in the lines are set based on peak demand estimates or experience, then extra capacity is provided to compensate for non-value-added time for setup changes, rework, new product launches, quality problems and trouble shooting for gearing up for building unusual products,. The equipment will be set up and products will be built to satisfy the forecast. The MP is also characterized by long runs of identical products based on the principles of economies of scale and Frederick Taylor's specialization of labor. Once products are manufactured they will be sent to the warehouses or distribution centers, which will await anticipated orders. This is a simplistic view of MP apparel manufacturers. In the assemble to order MP practice, after receiving an order the manufacturing entity starts purchasing fabrics, accessories and sub-systems, waits for the goods to arrive, and then assembles them into products. The leadtime will increase with any additional supply chain link which has to go through the same process of ordering and waiting for its parts. The manufacturing in a 'batch' and 'queue' environment causes the delay at every workstation in the manufacturing process. MP considers batches or lots as a good way to manufacture apparel to overcome the 'setup' cost. Setup is considered as all the tasks that have to be carried out to change over equipment and materials when changing from one part or product to another. In apparel production this could be setting up machines, programs and production units, organizing garment parts, supplying of necessary accessories to stations and checking quality. Manufacturing MP apparel in batches or bundles causes the cost and leadtime to rise due to set-up costs, lower machine utilization, longer throughput time, higher WIP inventory, low space utilization, hidden quality problems, disruptions, and less flexibility. Based on the literature, the current business practice of demand and supply for replenishment of domestic sewn products under the MP concept can be graphically shown as in the Figure 2.2. One variation of this model which is not shown is that the retailer can obtain goods directly from the manufacturer as a store direct shipment even with the availability of the distribution center.

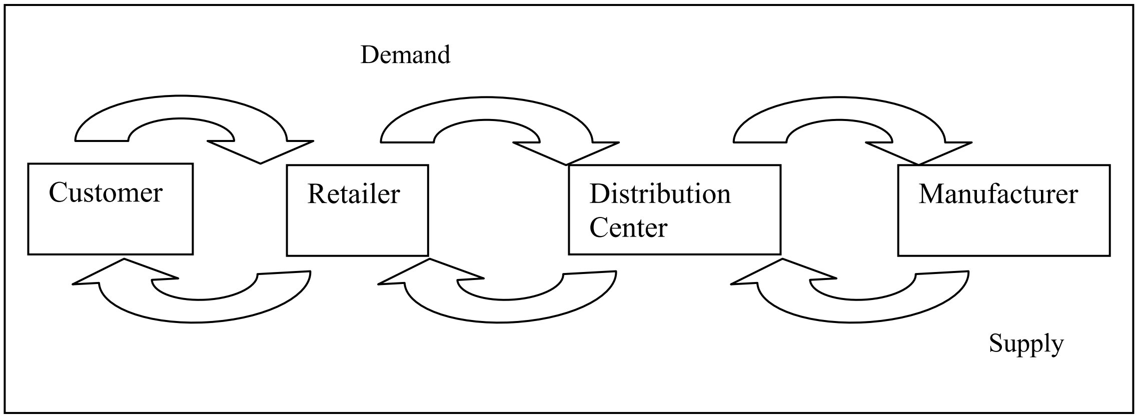

Figure 2.2: Replenishment of domestic sewn products under MP system (C.G. Carrere, 1997)

As per Nuttle, King and Hunter (1991), in their model that simulates the seasonal apparel retailing process, the functional diagram is shown as in the Figure 2.3. The model depicts that after an initial supply, a continued process of reordering and replenishment practice takes place based on the mass production manufacturing environment.

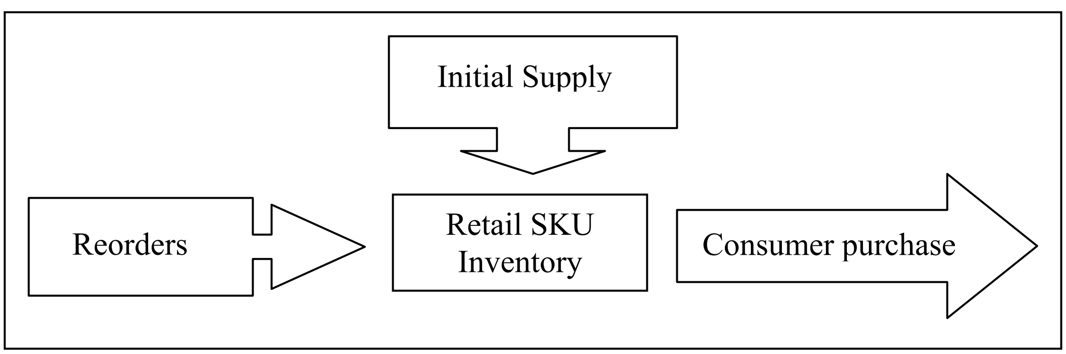

Figure 2.3: Functional diagram for seasonal apparel retailing (Nuttle, King, & Hunter, 1991)

Customer purchasing decisions are based on a complicated set of interacting factors (Nuttle et al., 1991). Even though low cost, high quality and quick delivery are simply qualifiers in the purchasing process, manufacturers must personalize products to meet customer needs and simulate market demand. To achieve this goal, manufacturers must adopt new strategies such as MC. It is important to understand the available apparel MP manufacturing systems and their characteristics in researching the mixed MP, MC apparel manufacturing. The next section explores the existing apparel manufacturing systems and their characteristics in detail.

2.1.1.1 Apparel Manufacturing Systems and System Attributes

The characteristics of different manufacturing systems are discussed and compared. This comparison is used in developing a comprehensive attribute comparison table[1]. The attributes which are significant for the customized apparel manufacturing business are identified. These attributes and the apparel manufacturing system matrix is developed to be used as an instrument in researching the mixed MP and Mass-customized manufacturing model. The production layouts for the manufacturing systems are graphically shown in the Appendix A.

2.1.1.1.1 Characteristics of Apparel Assembly Systems

The Make-Through system was essentially the traditional method of apparel manufacturing in which an operator makes an entire garment one garment at a time. Although quick throughput time (TPT) and easy supervision is achieved, low productivity and higher costs made the system not very useful for high volume

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[1] See Chapter 6: Research Findings, Results and Discussion

production. The Make-Through system needs a highly skilled operator and is suitable for "one-off" production such as is required in custom clothing (Johnson-Hill, 1978).

2.1.1.1.1.1 Apparel Assembly Systems and System Description

- **Straight Line**

This was considered to be the first successful attempt to organize workflow in the mass production of apparel that was popular through 1940's in the United States, but relatively few apparel plants appear to be using it today. The unit of production is a single garment passing through the respective sequence of operations mostly using conveyors or chutes. If required one operator can feed more operators in the line via sliding down using chutes and sometimes called "progressive lines" or "synchro flow systems". The layout must be carefully planned and chutes custom made. It is sometimes difficult for an operator to leave the workstation without moving a chute where other layouts do not have this constraint (AAMA, 1988). The operators also can be laid out on either side of a conveyor or a central fixed table (Johnson-Hill, 1978). As the system does not expect style changes, extra machines need not be planned but a good maintenance system needs to be in place with back up equipment and parts. According to Johnson-Hill (1978), "one cost item which is eliminated on a conveyor or straight line system is bundle handling time though this is more than offset by the less efficient handling of the individual garment parts".

- **Straight Bundle System**

The production unit is a bundle of cut garment parts. The bundle size is usually determined by the plies in the cut or the weight of the fabric. The bundle is opened by the operator, carries out the operation on each part, cuts and processes the work ticket and re-ties the bundle before it is being transferred to the rail or the bin where the bundle is redundant until the next operator is ready for it.

- **Progressive Bundle System (PBS)**

This was evolved from the straight bundle system as a way of reducing the time for bundle tying and un-tying. This system surfaced during 1930's and has been the prevalent system since (Cameron, 1992). Bundles of cut parts are transported to the sewing room and given to the operators scheduled to complete the operation. An operator is expected to perform the same operation on all the parts in the bundle, re-tie the bundle, process the coupon or the electronic bundle ticket, and set it aside or put it in a bin for the next operation. Bundle routing identifies the basic operations sequence of production and the work centers where the operations are to be performed. Bundles can be moved on rolling trucks or in clamps. The progression of the bundle unit is based on product flow where each bundle truck flows sequentially to the next operation or to the bank of work ahead of the next operation. To accommodate the change in styles the system was further developed with the "skill center" concept. With this system the operations are grouped into sub-assembly sections after which the work is loaded on to trucks for final assembly and processing. According to Johnson-Hill (1978), this system was called "Interflow System" which used work transporters as the way of transporting bundles.

- **Transporter Systems**

Transporter systems were known for some time and were popular for specific use such as for "small" garments. These systems use one or more conveyor belts running between two rows of sewing workstations. "Bundles of work-in-process are carried in tote boxes which are staged between operations in a flow rack. Tote boxes are removed from storage, placed on the conveyor and routed to the operator as needed" (AAMA, 1988). Once the operators finish working with the bundle, it will be returned back to the storage using the lower conveyor and will be routed to the next operation as planned. An operator controls the distribution of the tote boxes to the respective operators.

- **Unit Production System (UPS)**

The UPS is a type of line layout that uses an overhead transporter system to move materials to workstations, which can be manual, powered or a mixture. In most cases (currently) the system is linked with a computerized control and management reporting system. Cut parts for one unit of a style are loaded directly from the staging area in the sewing room to a hanging carrier, considering minimal future handling. All the parts for a single garment are moved by means of a hanging carrier that travels along an overhead conveyor, which consists of a main conveyor and accumulating rails for each workstation. Assembly operations take place while parts are on the hanger. This system can be considered as a mechanization of the flexible work groups (Hill, 1995). Sequencing of work and system balance is accomplished by the computer controls, which track the movement of individual clamps through the system. Integrated systems have online terminals located at each workstation to collect data on each operation. The terminals at each station enable the central control center to track each unit at any given moment and provide management with data to make immediate decisions on routing and scheduling(Glock & Kunz, 2000). Bar codes or radio frequency devices are used to monitor the position and sequence of individual carriers (AAMA, 1988), (Switchtrack-Systems, n.d.).

- **Modular Manufacturing System** (Also, called Cellular Manufacturing Units, Compact Work Teams, Flexible Work Groups, Toyota Sewing System (Glock & Kunz, 2000)).

This system consists of small groups of highly cross trained operators organized into modules or work cells with high operator empowerment in making decisions to best suit the manufacturing circumstances. The work teams may establish the workflow and specify method of handling. Because it operates as a 'pull' system, demand for work will come from successive operators in line to process the garment. "Workflow within a module may be with a singe piece hand-off, Kanban, or bump-back system"(Glock & Kunz, 2000). In the hand-off system, each production operator completes the task and passes a single garment or a small bundle to the next operator using hand-off. In the second simulation strategy minus "Bump-back", workers are authorized to work and transfer the product in a work station using a marked space when subsequent station's marked space is empty. In the bump-back method a production operator is replaced at any point in the cycle with the subsequent operator who has just finished the cycle with the production unit progressing forward. Also, it highlights teamwork, quality control at the source and, moreover shorter throughput times. The production unit can differ from a single garment to small bundles of two to five units. A work module can be created to assemble an entire garment, or to produce sub-assembly units of a more complex product. Manufacturing layout is generally U-shaped with more machines than operators. To facilitate movement among the work places, operators usually work at a standing position. When the bundles are used, operators can work in a sit down position. When an operation is backed up, the operation feeding it is stopped and that operator moves to the subsequent operation in order to clear the congestion further down the line and continue to pull work through the module. Kanban systems, which limit the build up of work in front of an operation, can be used for such a situation. Order process tracking needs a control system (AAMA, 1988).

2.1.1.1.1.2 Apparel Assembly Systems and Throughput Time

- **Straight Line**

Quick throughput can be considered as the primary advantage, which is often as little as the labor content. “The operations are broken down to fit as nearly as possible, a fixed cycle time, and the speed of the conveyor, if used, is set to suit this cycle” (Johnson-Hill, 1978).

- **Straight Bundle System**

Even with “a good control system and good management and supervision, the work-in-process in the bundle system can be as much as four or five days. More typically, it amounts to 15 or 20 days for a garment with only 20 standards minutes of labor content" (AAMA, 1988). High non-productive time is involved due to bundle handling and due to the bundle size and work flow, it can amount to an average of 8% according to a study made by the Shirley Institute in the United Kingdom (AAMA, 1988).

- **Progressive Bundle System**

A large work-in-process (WIP) level is required. PBS with the skill centers approach needs even larger WIP level to overcome the bottlenecks thus further extending TPT.

- **Transporter Systems**

High WIP is maintained as the tote boxes are placed one at operator, one in reserve and few in the storage for each operation causing the throughput to be delayed.

- **Unit Production System**

As the production unit is a single garment, the unproductive time such as tying/untying bundles and clipping work ticket is eliminated. Further, as the hanging garment is presented to and removed from the operator, the material handling time is reduced. With the low WIP, elimination of bundle handling and clerical time and with computerized production and payroll data acquisition, the TPT is reduced. The capability of automatically sorting matchable items help to eliminate matching delays. The waiting time is reduced by good work balancing to the extent that "one supplier of UPS equipment reports an average of two-to-three minutes of total waiting time per operator per day "(AAMA, 1988). According to Hill (1992), Clemson Apparel Research Center has found that operator productivity can be improved by 18% and direct labor excess can be reduced by 34% in comparison with the PBS (Hill, 1992).

- **Modular Manufacturing System**

Shorter throughput time is the major expectation of this system with minimal WIP inventory with the Just-In-Time (JIT) delivery philosophy, which means that work is "pulled" through rather than "pushed" through.

2.1.1.1.1.3 Apparel Assembly Systems and Operator Skills, Payments, Productivity and Related Characteristics

- **Straight Line**

Operators are paid by the line rate irrespective of individual effort and determined by the output at the end of the line.

- **Straight Bundle System**

Operators are allowed to work with their own pace and earn the piece rate based on the WIP available. Bundle system rewards high individual productivity.

- **Progressive Bundle System**

With a PBS skill center approach, the general absenteeism rate reduces and provides convenience in balancing the line. Segmenting the production line into smaller, specialized team of operators still provides the ability to work on individual incentive pace.

- **Transporter Systems**

This eliminates manual handling work to a great extent in terms of part transportation which also allows the bundle size to be increased. Some systems can keep a track of operator production thus can eliminate work ticket manipulation.

- **Unit Production System**

Frequent job change is required to balance the unit so that more utility operators with cross training are required. This is true even to overcome the problem of absenteeism. The supervisors are expected to be given more decision-making authority. Production is expected to be moved smoothly as there is no inventory to overcome bottlenecks. Worker morale and team spirit tend to be improved causing reduction in labor turnover and absenteeism. The individual operator and control center are able to monitor individual work history. Based on the collected data, the system is capable of calculating operator earnings, efficiencies, etc. In the latest UPS systems each hanger may have an E-Prom attached to facilitate tracking. This micro-electronic technology provides a transportable based memory, INAMAX, on the UPS system or INACARO for tracking off-line work-in-process (AAMA, 1988).

- **Modular Manufacturing System**

The modular manufacturing system consists of a self-managed group of cross-trained operators sharing the operations by filling the next immediate operation with its capacity. “The ability of a team to move smoothly and flexibly between operations without outside direction, is the key to achieving maximum performance from a module” (AAMA, 1988). Group incentives are practiced in place of individual piece rates. However, in the case of sit down modules with bundles, individual achievement is recognized within the group with different base rates for different operations, and often combined with group or quality incentives. As operators switch work places, they will loose the individual productivity compared to work specialization.

2.1.1.1.1.4 Apparel Assembly Systems and Quality Control, Assurance and Flexibility

- **Straight Line**

The main disadvantage is its inflexibility where a minor style/product change needs major layout revision. This is because the restriction of having to break the garment construction into operations of equal cycle time (Johnson-Hill, 1978). The least productive operation controls the line productivity. Though tight and close line balance is achieved with the combination or movement of work elements, slack or lost times for some operations are inevitable. It is relatively easy to control the level of quality in the line (AAMA, 1988).

- **Straight Bundle System**

Less prone to style changes and very low market responsiveness can be achieved with this system.

- **Progressive Bundle System**

Handling the variations in styles with skill centers require extra machines and cross-trained operators. Quality defects can be hidden in bundles.

- **Transporter Systems**

Due to layout restrictions, variable styles may not be possible to handle at once as the sewing machines are arranged along the conveyor according to a particular style's operation sequence.

- **Unit Production System**

Some manufacturers refer to the UPS system as a flexible system. However, fixed physical configuration limits flexibility. Repairs in the system tend to be lower due to the reduction in WIP, immediate visibility of problems and accountability of all operators.

- **Modular Manufacturing System**

Excess machinery with various special features and attachments are necessary to operate with style variations. Operators take the responsibility of the product quality at source and peer pressure maintains an effort to have it right first time to avoid affecting the output and group earnings. The modular system is less impacted by absenteeism because operators are cross-trained and can easily fill in for the absent operator.

2.1.1.1.1.5 Apparel Assembly Systems and Other Characteristics

- **Straight Line**

Some manufacturers have used air floatation or belt conveyors on the chutes to improve the workflow. Specified automated or mechanized equipment suggestions may be ignored, as increased production will cause an out of balance line. A machine breakdown can be critical, as it will affect the productivity of the complete line (AAMA, 1988). Organization of special workplaces can be somewhat impractical as garments are handled individually because of proximity of the conveyor table, if any (Johnson-Hill, 1978). Some straight-line systems use manually operated overhead rail systems to transport the material from one workstation to the next, e.g. "Switchtrack" (Switchtrack-Systems, n.d.).

- **Straight Bundle System**

To overcome the balancing problems associated with differing rates of productivity at different operations and operators having different skill levels, there must be an overflow area to hold WIP between operations.

- **Progressive Bundle System**

Each bundle receives a ticket which consists of a master list of operations, corresponding coupons for each operation, style number, size, shade number, list of operations for routing and piece rate for each operation. Firms may use electronic bundle tickets or smart cards that accompany each bundle that are swiped at each workstation along with operator identification card to transfer production/operator information electronically. “This system may allow better utilization of specialized machines, as output from one special automated machine may be able to supply several operators for the next operation” (Glock & Kunz, 2000). Unlimited scope for special work places may increase the output per unit area (Johnson-Hill, 1978).

- **Transporter Systems**

This system was popular in producing small size products such as swimwear and bras. The systems may use floor-mounted conveyors using the live storage, flow line or carousel principle with different levels of inclinations with belt or rolled track.

- **Unit Production System**

Though the capital expenditure is high, the reduction of inventory carrying cost causes the system to recover costs rapidly. Spare machinery is required to avoid balancing delays to operate with low WIP (AAMA, 1988). In a ‘headline’ system, the hanger with components can be accumulated at individual workstations and in a ‘closed loop’ configuration it allows the hangers to bypass workstations routing to the desired workstation. A straight line can be of an open loop configuration where product flows from operation to operation from loading station to final assembly. From the manufacturing viewpoint, a straight-line UPS system operates more efficiently for long production runs and infrequent changes in color and style. While a headline UPS will operate efficiently for long production runs, it is more appropriate for a highly diverse product range and permits multiple styles to be assembled simultaneously (Little &

Careere, 1986). One of the important capabilities that UPS has is real-time production control. In most systems "electronic data collection provides payroll and inventory data, immediate tracking of styles and costing and performance data for prompt decisions." (Glock & Kunz, 2000).

- **Modular Manufacturing System**

Though the modules are not fixed in size, they are generally limited to a size organized around a logical breakdown of operations. The idea of satisfying the customer is maintained as each operator is considered the customer of the previous operator. The management must set realistic goals relative to quality and throughput time, which is communicated, to the module team. The team then develops the best approach to achieve the goals with the high level of supervision. Standup units need elevated machines, work surfaces and special foot controls for easy operation. As discussed in the TSS product brochure (Anon., 2003), the bump-back or Toyota Sewing System (TSS) approach was developed in 1978 by the Toyota Sewn Product Management System from the primary concept of Toyota Production System and became widely used team-based manufacturing system (Vincourek, 1990). It is a stand-up module with flexible work zones in which individual operators work. Operators need to be cross-trained in up to 4 different successive operations enabling them to shift from operation to operation until the next operator is ready to take over. This arrangement frequently uses a 4 to 1 operator to machine ratio. Due to rapid TPT, less real time production control is required. As discussed by Mitchell (1988), the TSS and the Juki's Quick Response System was introduced at the JIAM show in 1987 which provide the author with evidence of TSS being used to develop other similar sewing systems by other companies (Mitchell, January 1988). The discussion of “A case study and definition of modular manufacturing” by Career and Little (1989) suggests that the modular manufacturing system for apparel has evolved into practice by mid 1980’s and became popular as a team-based manufacturing system (C. G. Carrere & Little, 1989). The advantages of a Modular production system such as flexibility, fast TPT, low WIP, employee ownership for the process, empowered employees and improved quality at the source has lead to use this system for the mass-customized approach of business (Glock & Kunz, 2000).

2.1.1.1.2 Apparel Assembly System Attribute Comparison

In addition to the above information, results of research studies yielded the following information with regard to system attributes. Table 2.2 was formed by Clemson Apparel Research with plant statistics collected on research projects, designed to document the comparison of PBS and both flexible work groups (FWG-Modular) and UPS (Hill, 1995).

Table 2.2: Comparison of attributes of PBS with FWG and UPS (Hill, 1995).

Attributes	PBS	FWG	FWG % Improvement	UPS	UPS % Improvement
Net Productivity			+13.4		+18.4
Direct Labor Content			-0.3		-9.7
Direct Labor Efficiency			+7.7		+4.6
Direct Labor Excesses	13.3%	5.7%	-57.1	8.8%	-33.8
Quality (% Defective)	7.2%	2.5%	-65.3	6.4%	-11.1
TPT (Days)	14.9	4.3	-71.1	5.9	-60.4
Attendance	94.6%	97.2%	+2.6	95.6%	+1.1%
Turnover	50.9%	30.7%	-39.7	35.9%	-29.5
Space Utilization Sq Ft/Operator	110	69.4	-36.9	78.4	-28.7

Armfield (1994) developed a process comparison as shown in Table 2.3.

Table 2.3: Comparison of attributes with assembly systems (Armfield, 1994)

Attributes	Team (No of operators)	Batch Size (No of units)	Leadtime (Days)	Skills per Operator	Labor/ Overhead
PBU		30-50	7-10	1.1	
MIL (Managed Inventory Line)	40-100	30-50	3-5	1.5	+2%
UPS	20-40	1-3	<1	1.1	
Mods	7-15	3-12	1-2	3.0	+2%
UPS-Teams	15-20	1-3	<1	2.0	+1%
Single-Unit	7-15	1	<1	3.5	+7%

According to Armfield (1994) in his article “Flexible Customer Response”, except for the single unit pass through the cost difference between systems is not significant. However, as the batch size and the leadtime decreases, the number of operator skills required becomes higher. The cost has been computed using a standard cost approach without taking into account the value of time and velocity (Armfield, 1994).

Fralix (1999) reported on the results of a study of sewn product plants that had converted into team based manufacturing from traditional batch manufacturing. The team based manufacturing offers consistent WIP reduction and TPT improvements from weeks to days. Floor space requirements are typically reduced by 25-30 % with an increase in operator earnings (Fralix, 1999).

Cameron (1992) has tabulated the results that can be obtained from a successful implementation of modular manufacturing cells as shown in the Table 2.4. The comparison is done with other traditional manufacturing systems that were discussed above.

Table 2.4: Attributes for Modular Manufacturing compared to other systems (Cameron, 1992)

Attributes	Results
Through-put-time in sewing	Decrease 50-75%
Overall work-in-process	Decrease 35-75%
Unit cost	Slight increase – slight decrease
Operator earnings	Increase 0 – 23%
Plant efficiency	Slight drop – 28% increase
Quality	Slight improvement – 17% improvement
Absenteeism	0 – 38% reduction
Turnover	0 – Major reduction
Indirect labor	Reduction of 25 – 50%

The following Table 2.5 shows some attribute comparisons that were compiled by the Technical Advisory Committee of AAMA (1988). The relative strengths/advantages of each systems major parameter have been compared with a scale of 5 being strongest and 1 being weakest.

Table 2.5: Attribute comparison among manufacturing systems (AAMA, 1988)

Parameters	**Production System**				
	Line	**PBU**	**PBU Skill Center**	**UPS**	**Modular**
Product flexibility	1	2	5	3	4
Extra machinery	5	2	1	3	2
Through-put-time	5	2	1	4	4
Vulnerable to absenteeism	1	4	5	2	2
Quality control	5	1	1	4	5
Space Utilization	5	1	1	3	5
Bundle & clerical time	5	1	1	5	4
Employee involvement	4	1	1	4	5
Indirect labor required	4	1	1	4	5
Individual Productivity	1	5	4	4	2

Kurt Salmon Associates (KSA) compared the attributes of UPS with Progressive Bundle System for a style plant as shown in the Table 2.6 below.

Table 2.6: Comparison of parameters for UPS and PBS (Kurt-Salmon-Associates, 1997b)

Factor	**PBU**	**UPS**
Throughput time	4-5 weeks	1-2 weeks
WIP	2-3 hours/operation	15-20 min/station
WIP costs	Variable	Saving not significant
Finish goods costs	Variable	Can be significant, often not relevant
Bundle handling	3-6%	Nil
Reduced cycle time	-	5-7% time reduction
Defect rectification	2%	1%
Waiting time	2-3%	12-15%
Job transfers	3-5%	6-10%
Plant efficiency	70-80%	60-70%
Excess costs	15-20%	40-70%
Supervisor/operator ratio	1:30	1:20

2.1.1.1.3 Apparel Manufacturing Strategies

2.1.1.1.4 Flexible Apparel Manufacturing

Flexible apparel assembly technologies have been increasingly in demand with the evolvement of the new apparel business environments such as mass-customization. The concept of apparel manufacturing flexibility is not new and has been on research agendas for the last few decades. Manufacturing flexibility in the apparel industry has ranged from made-to-measure tailored clothing shops to plants set up to manufacture volume of one single product. The need to shift towards apparel manufacturing plants, which offer multi-product flexibility thus faster market responsiveness, is inexorable. In the past, the change from one style to another even with a smaller change was considered as a disruptive event in apparel assembly as the factories wanted to continue production without changes over a longer time. However, the numbers of "one-product" apparel companies have reduced rapidly. The shift towards apparel manufacturing plants offering multi-product flexibility and faster market responsiveness has become the key towards practicing mass customization. Therefore, the challenge was to develop more flexible apparel manufacturing facilities. The requirement is to respond fast with the right product and with the magnitude and multitude of SKU's involved in the apparel business. It is not economically feasible to expand open stock enough to provide quick response order replenishment from inventory. Flexible apparel manufacturing with the ability to quickly produce what is required is the viable answer.

2.1.1.1.4.1 Flexible Manufacturing System Features for Apparel

To develop a FMS, material, machinery, attachments and labor need to be adequately pre-planned to assure availability in the right quantities at the right time. The pre-engineering process to decide the method of production with the work place, machine, skill requirement and the time is very important in achieving the goal. The changes in the manufacturing floor are required to be done rapidly. Retraining needs must be minimized by deskilling jobs where possible. Clear instructions for all the jobs involved and motivating the operators to learn fast on new jobs is very important. A higher degree of operator cross-training will lead to easier problem solving for bottlenecks. Communication between operators and other support people such as supervisors, line managers and mechanics is paramount. The flexibility of the process needs to be covered throughout all the functions, not just cutting, sewing and finishing (AAMA, 1990b).

To achieve the task, the industry not only needs to concentrate on the factors discussed above, but also starts looking at the technological advances and how they can be accommodated with the existing and new apparel manufacturing systems. In doing so, flexible manufacturing system requirements such as reduced total TPT, smaller lot sizes, quality at source, reduced level of inventory, broader style/fabric capability, cross training of operators, greater employee involvement, new forms of employee motivation and compensation, more emphasis on group performance, problem prevention/anticipation technique development, continues product/quality improvement, effective information systems and computer controls with proper function integration, may need to be considered. Further, combined manufacturing systems with different manufacturing techniques can be incorporated in a single plant to achieve flexibility. "For example, it is not unreasonable to expect that one factory would find it best to use Progressive Bundles in the "parts section" and Modular in "assembly" (AAMA, 1990a).

If the company requires a fast turnaround time of a few minutes per garment, then the management might choose a stand up module using the bump-back method, with a machine to operator ratio of 4 to 1 and with a WIP level of zero to two pieces between workstations. On the other hand, the company may use a sit down module using the hand off method with a machine to operator ratio of 1.5 to 1 and a WIP level of 10 to 12 units between workstations (Hill, 1995). To implement a flexible work group, management procedures must be adopted to reduce WIP levels by assuring that machinery, technology systems and work schedules are properly administered for immediate response to routine workflow constraints. The operators must be cross-trained for technical, managerial and behavioral aspects. With the assembly technological advancements, technical training becomes a vital part of the apparel manufacturing process. Employee empowerment is the basic principle that typically sets flexible work groups apart from other manufacturing systems. Also, this helps in WIP reduction and creating team atmosphere. Even though a highly flexible apparel assembly system is encouraged, there needs to be a balance between the productivity requirement and the extent of flexibility. The research paper "A case study in apparel automation" has researched the relationship of flexibility and productivity with literature from the Singer Machine Company and explained this balance as shown in Figure 2.4 (McPherson, Little, Clapp, & Seyam, 1993).

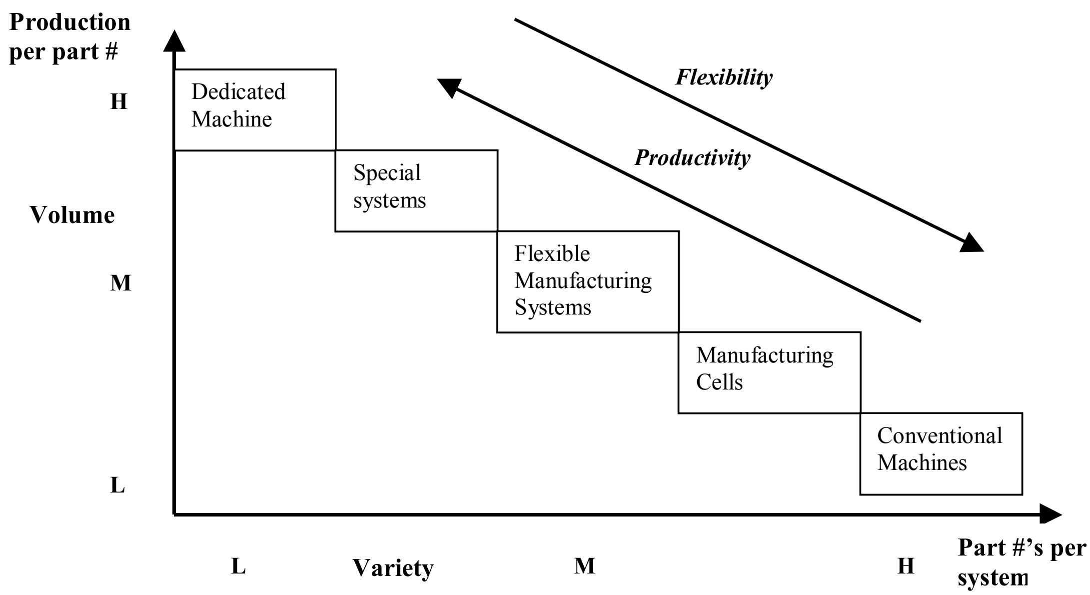

Figure 2.4: Productivity and flexibility in apparel assembly systems (McPherson et al., 1993)

Various FMS and strategies have been developed over time. Popular examples are U-Shaped lines, Cellular manufacture and Toyota Sewing System. Some advantages that literature discusses about changing the shape of the lines from straight to U-shape are;

- Visual control - Members of the line can see the full operation and provide a great group ownership and ability to work in a team environment.
- Problem awareness - As the members in the line see and hear each other, faster problem identification and solving is possible.
- Helping out - As the stations are closer, operators can help each other in case of bottlenecks.

- Skipping steps - As the stations are close together, orders that even do not have all the steps can be processed easily (Anderson, 2003).

The concept in the Cellular manufacturing is that flexibility can be achieved through dedicated cells which can be permanently configured so that within a product family the set up can be eliminated. The operational procedure of TSS is discussed under the system description of modular manufacturing.

With experience in implementing the FMS, the industry has further moved in search for systems such as Flow Manufacturing, in combination with latest technological developments.

2.1.1.1.5 Flow Manufacturing

Flow manufacturing, also named as synchronous manufacturing, theory of constraints, agile, lean or continuous manufacturing, is a manufacturing strategy that uses a "pull-driven" strategy, which is becoming popular in many industries including apparel. The idea of a synchronous flow manufacturing system has been in existence for decades and has been addressed in the literature (Johnson-Hill, 1978). "Nearly half of the fortune 500 companies notably from aerospace, electronics and automotive sectors have used this concept with great success" (Motwani & Mohamed, 2002). Also, this is considered as a demand based manufacturing strategy to improve the delivery performance of a high velocity order (Donovan, n.d.).The principal requirement of this strategy is to synchronize the daily production rate with demand by properly sequencing items on a flow line that are replenished frequently by suppliers at the point of use. One of the key factors for the success of a flexible system is the management of the product flow. When the flow of materials through the assembly stations is carefully synchronized, with materials moving continuously and smoothly from one operation to the next, it facilitates short manufacturing leadtimes and little waiting (Ahmadi & Wurgaft, 1994). This concept provides the inventory to be kept to a minimum with goods made to demand (or made-to-order) and cycle times falling within the order to delivery response times. Also, the used flow space can be dramatically reduced and the recurring quality defects can be eliminated (Anderson, 2003). "With flow, the work moves from one operation to the next one piece at a time. There is a steady stream or flow of work passing through the plant more or less un-interrupted" (Motwani & Mohamed, 2002). Therefore, flow manufacturing represents an extremely flexible alternative to traditional material resource planning type or production-by-lot manufacturing. It provides the ability to change product mix and volume and match specific customer requests rapidly. Implementing it requires significant changes in production process and operator training. But the advantages of improvements in productivity, quality, and flexibility override the cost and effort. This system expects to remove all the non-productive queue times. It is an important task to identify the relationship between the assembly technologies available or assembly technology developments and the possibility of adopting a flow manufacturing strategy to achieve responsive apparel replenishment for mass customization. If setup can be eliminated or reduced to a level that can eliminate the need to manufacture in batches, the parts can flow one piece at a time. The one piece flow aspect of this system is the key for rapid throughput, little or no WIP inventory, and rapid quality feedback which are essential for mass-customized apparel manufacturing. With regard to the raw material and other accessories that are needed for manufacturing, “dock-to-line deliveries directly to all points of use without the incoming inspection is a key element of flow manufacturing, lean production, build-to-order and mass customization “ (Anderson, 2003). To accomplish this aspect, the suppliers may need to be assured for quality at source.

The following aspects need to be considered with the flow-manufacturing concept (Donovan, n.d.; Flow-Manufacturing, n.d.; Motwani & Mohamed, 2002):

- Different products go through the system
- Amount of parts go through different workstations
- Number of workers needed
- Which operations to be performed when the product is processed
- Workstations required to process the mix of products
- Necessary work done by employee
- Necessary work done with equipment or machinery
- Machine preparation time for production
- Time needed for material movement between station
- Quality control at each workstation
- Time required to process each product at each workstation
- Amount of good and defective parts at workstations
- Takt - Rhythm of the line: indicates how often a part is moved to the next process
- No bottlenecks or wasted time
- Driven by customer demand and thus high flexibility is needed

- Linearity – Number that indicates how much time is needed to reach a daily production goal. Achieving linearity is expected with a small inventory warehouse called “raw in process”.
- Adequate suppliers that offer high quality products.
- Individual departments are combined into single order fulfillment departments.
- Work groups or cells – Multi-skilled, empowered – Responsible for tasks and quality.

2.1.1.1.6 Quick Response Manufacturing

Based on the drawbacks of the apparel manufacturing systems to meet the volatile customer demand, QR apparel manufacturing became paramount important. The demand simply is to deliver the goods on short notice, in small lots and a broad assortment. This was a more effective competitive strategy for apparel companies demanded by the volatile apparel markets that need large products variation. Quick response manufacturing (QRM) is identified as a company wide strategy that pursues the reduction of leadtime in all aspects of company’s operations. This strategy is explained in two contexts; externally as responding to those customers’ needs by rapidly designing and manufacturing products customized to the needs, and internally as reducing the leadtime for all the company’s own operations and tasks resulting in improved quality, lower cost and quick response. QRM is a practical strategy, that embodies the mindset of pursuing leadtime reduction, along with detailed management principles, manufacturing methods, analysis techniques and tools, and step-by-step methodology to achieve the desired reduction in leadtimes (Suri, n.d.). During the last two decades just-in-time manufacturing techniques became popular and have been adopted by many companies. More recently the strategies based on these Japanese principles were named as Lean Manufacturing (Womack & Jones, 1996). According to Suri (2003), QRM also finds its roots in strategy used by Japanese, later known and documented by American authors as "time-based competition" (TBC). The underlying principle of TBC is the use of speed by a company to gain competitive advantage thus deliver products or services faster than its competitors.

The literature discusses the similarities and differences of Lean Manufacturing and QRM in wide variety of aspects (Suri, n.d.). Elimination of waste, implementing flow and implementing a pull system are some of the known strategies in Lean Manufacturing. Relentless reduction in leadtime, implementing operation flexibility, more flexible flow manufacturing, custom design and fabrication instead of maintaining a large inventory for pull are popular strategies in QRM. As literature argues, lean manufacturing can be successful in producing for a limited degree of customization and market with comparatively a stable demand (Womack & Jones, 1996) while QRM is appropriate for the needs of customization and changing markets (Suri, n.d.). The demand activated manufacturing architecture (DAMA) project carried out by the Sandia Corporation and Textile Clothing Technology Corporation, developed an inter-enterprise architecture and collaboration model for supply chains that will enable improved collaborative business across the integrated textile complex (retail, apparel, textile and fiber sectors). This will be a useful model for mass customization that will provide information for an improved collaborative business across the apparel manufacturing-based supply chain (Sandia-Corporation, October 2000). As per Hunter et al. (1991), QR strategy for apparel requires a “collapsed and responsive supply system, smaller initial store inventories of garments, point-of-sale tracking, barcoding of merchandize and electronic data interchange, continual re-estimation of season’s customer demand and frequent reorders on the vendor that allow matching of the stock keeping unit assortment being offered to what the customer wants”. This requirement can be better served today with the new information technology using Internet, Radio Frequency Identification (RFID), etc. QR and traditional retailing performance has been compared using stochastic simulation modeling (Hunter, King, & Nuttle, 1991). Research on the benefits of QR implementation (Hewitt Jr., Hunter, & King, 1991), and cost comparison for QR and traditional apparel suppliers (Pinnow & King, 1997) is discussed in the literature.

2.1.2 Assembly Technology Infrastructure and Manufacturing System Response for MP Apparel Manufacturing

Research in mixed MP, MC apparel manufacturing, demands the knowledge of available technology infrastructure. This section of the literature review will address this important area particularly related to apparel assembly and discuss in detail the various approaches of technological enhancements to introduce flexibility, quality and fast through-put which are essential factors for mass-customized apparel manufacturing. The discussion will further lead to identify other supporting technologies, as author suggests, will play a major role to achieve success in mixed MP, MC apparel manufacturing.

2.1.2.1 Introduction to Technology Move in MP Apparel Manufacturing – Historical Perspective

The following section discusses the various technological developments relative to pre-production and post-production sections of the apparel manufacturing process. With the discussion, it is expected to understand the relevant technological developments that will help in achieving success in mass-customization. “The apparel industry is one of the least automated industries in the world, and automation is one way of improving productivity in order to compete with the increasing threat from the low cost developing countries” (Leung, Black, & Lam, 1992). The apparel industry has tended to invest in new technology only if it would reduce labor or material costs, improve quality, or the training of unskilled operators. The cost was expected to be recovered within 2-3 years. At the customer end, the retail customers have been forcing companies to consider new technology such as barcode technology to improve the service level. Also, it can be seen that priority has been given to new MP manufacturing technologies such as FMS and philosophies such as QR (AAMA, 1991).

According to AAMA (1991), “from the beginning of the mass produced apparel industry in the U.S. until the 1960’s, technology meant cutting and sewing – primarily the latter”. The Singer sewing machine from 1850 that served the apparel industry more than 150 years was the prototype of the mechanical principles still inherent in today’s machines. However, new machines have been developed even without mechanical control such as the electronic sewing machine developed by ‘Tice’, which claimed that 90% of moving parts have been eliminated (Hasty, 1994).

Faster sewing machine speeds, attachments and workplace layouts were developed to reduce labor cost, increase operator productivity and quality. Technology advances for cutting and finishing were also aimed at better equipment to improve the efficiency of this labor-intensive industry. “Most of the improvements involved motors, cams, shafts, hydraulics, air-jets and similar mechanical elements” (AAMA, 1991). The other largest category of technology developments included the electronics which consisted of computers as well as control systems for a vide variety of apparel automation equipment such as pocket setters, buttonhole sewers, embroidery machines, etc. and other control systems such as real time shop-floor control systems. With the use of computer applications, apparel technology has made unparalleled advances.

The greatest impact in the pre- and post-production areas has come from computers. Beyond computers, electronics technology has also provided application-specific integrated circuits (ASIC) to control devices for collar stitching, etc. Even though technology’s focus was once upon manufacturing only, it has now spread to all elements of the process, affecting everything from product development through customer relations and service.

The aim for advances in technology has moved from increased machine speeds and reduced labor to enhanced flexibility and operator control over the sewing machines. This was caused mainly because of the adaptation of microprocessors and other elements of computer technology to sewing operations, and the need for manufacturers to respond to customer demands for more reliable quality and faster service. Manufacturers use these broad developments to set up more responsive sewing units, to deskill their operations, to reduce waste, and to improve quality (AAMA, 1992).

The advancement of optical devices with greater flexibility, reliability and low cost such as video and digital cameras, barcode readers, scanners and optical sensors, combined with other technology developments have been incorporated into apparel manufacturing applications, e.g. electric eye sensors to align the edges of fabric plies in spreading, optical scanners attached to an automatic cutting machines for automatic plaid matching and optics to trigger sewing in automated sewing operations.

From 1970s, progress was made in the application of mechatronics; that is, integration of mechanics and electronics, and mechanisms such as automatic thread cutters, pocket setters, long seamers, hanger systems and fabric layer cutters, etc. were developed one after another. From the latter part of the 1970s, applications of automatic equipment using micro-computers such as Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) made progress, and many types of automated machines emerged, e.g. auto-cutters and sewers. Robot technology also came into existence with other technological developments (Taylor, 1990). According to Nilsson (1983), "it is appropriate to characterize the present trend in sewing automations as creating under-rationalization through over specialization. This is fairly common phenomenon in the development stages of automation. It is due to our inbred technical inexperience in joining two very disparate technologies, like mechanics and electronics, into an integrated whole" (Nilsson, 1983). Over the time, with the developments of combinations of electronics and mechanics (mechatronics), these practices have changed not only in other industries but also in the apparel industry.

The garment manufacturing segment started automating to improve the manufacturing productivity as it was under pressure due to reasons such as increase in wage rates in this labor incentive industry, increasing costs from energy, materials and also capital and a considerable import penetration from the low cost labor economies with cheap labor costs. Therefore, the development and implementation of flexible clothing automation was an important need for the apparel industry (Leung et al., 1992).

Nilsson (1983), in his article,”FIGARMA – fully integrated garment manufacture, an extension of the concept of flexible manufacturing systems (FMS)”, forecasted a fully integrated and automated sewing assembly system which is based on automating the following elements using advanced computers and controls.

- Garment elements comprised of fabric parts and accessories and how they are being presented.
- Machine functions comprised of sewing machine and its functionality, which can be equipped with work-aids for positioning, guiding, thread cutting, etc.
- Manual operator functions which comprised of sewing operations such as pick up, position/guide, sew/feed/speed, and extract/discard.
- Transport/handling functions comprised of transfer of materials and parts.
- Supervisor functions comprised of functions of production line supervisor and controlling of individual operator and machine functions.

In his article, Nilsson also forecasted how these areas can be automated with a garment identity system, automated machine functions with multi-purpose mechanical sewing systems, automatic re-threading in sewing systems, automated operator functions and fully automated material transfer conveyor systems. The idea is to control the system entirely by an intricate interaction between the various components/nodes in the ‘intra-cell’ data processing network. This intra-cell network will be controlled by interaction between some higher-level networks. These predicted systems have achieved success to an extent that Japan was able to develop a fully automated sewing plant to manufacture ladies blazers. But, the problem was the lack of flexibility for changing raw materials and styles that is a prerequisite for mass-customization.

When the impact of technology on the post-production functions is considered, the process of maintaining traditional warehouses was fading away and a dynamic distributions center (DC) concept had been promoted. Order processing with allocation and delivery of the order to the retailers distribution center, or increasingly to the sales floor as store direct shipment, has taken place with improved leadtimes and responses to the customer requests. Inquiries regarding order status and delivery take place with an improved time with the revolution of the computer and communication networks. Further, the functions such as receipt and coordination of garments coming from many different sources (tracking of the finished goods and stock allocation) and distribution of the garments with correct packaging have become easy and efficient with the technology improvements related to barcoding, handling systems and computers. New developments in Radio Frequency Identification systems (RFID) are expected to revolutionize product tracking and inventory management. "The introduction of advanced equipment to help move goods in the distribution center has become secondary to the need for information–computer hardware and software to track and locate stock, allocate it to an order, print labels and tags, and produce manifests, packing lists, invoices and up-to-the-minute order status" (AAMA, 1991). Sophisticated logistics hardware included automated storage and retrieval systems, which have the capability of moving cases to random storage locations and retrieving them by the system on command. The stock location information could be real-time or batch processed in the DC and can be transmitted to the company computer in either real-time or batch mode. Computers today play a major role in packing and shipping of apparel in terms of maintaining updated databases with large amount of information ready to be used by the DC personnel and transmitting them using electronic data interchange (EDI) which saves significant amount of time in transmitting information to various destinations. Therefore, in post-production activities, both hard and soft technologies have helped the manufacturers to be more responsive to the markets. A strong integrated information and control system has connected the modern DC with the rest of the apparel enterprise and the customer. The transportation/logistics sector of apparel industry has enhanced its technological aspect to an extent that it can operate as "paperless" until shipping labels are printed, with the advancement of computer networks and communication technology.

While technology has had its greatest impact in every step of the pre-production area, growing emphasis has been given to integrating the pre-production, production and post-production processes during the last decade to achieve totally integrated information systems. This may be true for the present time except few companies have concentrated on integrating pre-, post- and production functions. Today, computers are extensively used in integrating efforts called "seamless solutions" to coordinate activities to bring new synergism to the apparel industry, to reduce the inventory build-ups, leadtime delays and imbalances that are inherent in apparel's batch processing methods. These technological advances must be clearly visible and will become very important for better response in MC apparel manufacturing systems.

The impact of information technology in apparel manufacturing has extended the managerial reach of executives in all areas of apparel, giving them the tools to challenge old assumptions and limitations, and achieve higher level of performance and responsiveness. New standards have been developed within the soft goods industry to enable its various parts to exchange information faster and more accurately, and thereby taken the advantage of new information processing technology. “The Voluntary Inter-Industry Committee on Standards (VICS) (now Voluntary Inter-industry Commerce Standards) developed common languages and symbols for product identification between retailers and apparel manufactures, and the groups such as the Textile Apparel Linkage Council (TALC), the Fabrics and Suppliers Linkage Council (FASLINC), and the Sundries and Apparel Findings Linkage Council (SAFLINC), sprang up to standardize communications among other sub industries in the soft goods chain” (AAMA, 1991). With the use of Telecommunication technology and the development of standards to control the exchange of information, Electronic Data Interchange became popular. Local Area Networks (LAN), Wide Area Networks (WAN) and satellite communication technology have enabled computers to share and access data and information easily, rapidly and accurately.

For the success of the apparel company the impact of technology is two fold: the impact that technology has had upon non-manufacturing activities such as product development, merchandising, costing, sourcing decisions, distributions and communications between apparel companies and their customers or suppliers and the impact upon the apparel production. Two decades ago the challenge was to have “quick response” which has not changed its meaning but evolved into “effective response”. As author suggests, the MC strategy demands a highly "flexible customized response" today. Low cost, reliable, quality manufacturing and sourcing became the practice among world class apparel companies, and they use modern manufacturing technologies to meet these requirements. The competition for obtaining skilled workers, inevitably encourages the deskilling of apparel operations with new technology. With the concepts such as Just-in-time, Zero defects, and value added management concepts such as TQM have offered much higher potential for the apparel manufacturing systems to be used with the technological advancements.

It is important to note that the new technology has made the possibility of creating new apparel manufacturing techniques and systems as the response to these technological advancements. Whether technology or technique, the important point is that these new developments have a profound impact upon apparel operations of every kind. The next section discusses the development of specific technologies in relation to apparel assembly, how different production systems use them, the development of technology applications for their needs over time and adoption of standards to reduce the risk of obsolescence and build a cohesive, integrated system to improve all functions. However, as most of the above discussion is related to MP, it is required to address how these technologies are applicable in achieving the needs of mass-customized apparel manufacturing at different stages of the manufacturing process. The reader should note that even though the system needs are discussed in relation to MP, they are also applicable to mass-customized apparel manufacturing.

2.1.2.2 System Needs and Technological Advancements in Apparel Assembly

2.1.2.2.1 System Needs

The need for moving from existing apparel manufacturing systems to using assembly technologies for MP, MC mixed manufacturing is based on many reasons. Assembly quality, productivity, cost and response times are the vital factors in making decisions to use these technologies. To improve the response to customer requirements, one has to consider these factors in combination with other supporting technologies. The theme of technological improvements in apparel assembly is that the product can be processed faster, sometimes with higher cost and sometimes with better quality. Using the already available technology infrastructure which will be discussed below and flexible manufacturing strategies, the question is whether it is possible to set up mixed MP and MC manufacturing units. Appropriate technology and production strategies may need to be used for appropriate stations in the mixed production unit. For example, all the stations may not need highest flexibility thus using the appropriate technologies (automated, deskilled, linked and combined), productivity, quality and fast throughput can be achieved. On the other hand, those high responsive stations that need high flexibility, quality and fast throughput may need to be equipped with technologies and production strategies such as skill centers, production modules, team production, multi-skilling, and operator empowerment. This approach is used by one company that participated in the case study approach for this research. Within the Unit Production System manufacturing environment, modules are developed with multi-skilled operators who make their own decisions for stations that need greater flexibility for various customized operations. For example, the company offers many options for customers to select various collar and cuff features thus the collar and cuff making modules in the production system are capable of making different collars and cuffs within the modules.

The advancements in apparel assembly technology have achieved "system needs" to variable extents by:

- Automation/Mechanization
- Linking/Combining operations
- Deskilling operators
- Material handling
- Supporting technologies

The following section discusses these advancements in detail. The idea is to understand these areas of technological developments in depth so that possible technologies can be suggested for the mixed apparel manufacturing system.

2.1.2.2.2 Technology Infrastructure to Support "System Needs"

2.1.2.2.2.1 Automation and Mechanization

Mechanization is the process of deskilling human labor with machines. However, this only encourages the work stations that are suitable for MP since the assembly which has been performed by human hand can be carried out more rapidly with repetition using dedicated machines. By the early 1900's, most sewing processes could be performed by machines. "Many patents for stitch forming devices and feeding mechanisms used in sewing machines today were issued in 1850's and 1860's" (Glock & Kunz, 2000).

Automation can be explained as a state of a system operating without external influence or control. Automated sewing systems are capable of replacing human labor by feeding the garment panels themselves from a stack, carryout one or more sewing tasks, and deliver the finished parts. Robotics is the most advanced form of automated technology. Robots are computerized, re-programmable, multifunctional manipulators designed to move materials, parts, tools or other specialized devices through variable programmed motions for the performance of a variety of tasks. These are suitable for stations that need less flexibility or stations that may not need flexibility for customization.

According to Johnson-Hill (1978), economic mechanization and work place engineering which are rules for better productivity, need to be applied to a maximum in staple and semi-staple production units. A similar approach may still be worthwhile for style and high-style units or customized units for some operations though the contribution to productivity is likely to be less due to short production runs and lack of continuity of design. Areas of greatest scope will be flexible engineering of the work place, and standardization of operations that can be used in various styles. However, excess mechanization, even that capable of reducing the cycle time, may hinder system flexibility (AAMA, 1978) which is an important factor to be considered in mixed manufacturing.

Sewing machines can be either 'general purpose', which is manually operated and can perform variety of operations, or 'special purpose', which is designed to perform a specific operation and likely to be semi-automatic or automatic. General machines need operator controls on both machine and materials. Flexibility is the advantage of a general purpose machine but they are often less efficient, less automated and require more labor.

Semi-automatic machines perform a cycle or operation automatically once the operator places the parts and activates the machine. Automated machines can complete an entire operation or series of operations with little or no operator presence and are more often used by firms that produce basic products. The shirt cuff making process is an example of an automated assembly process (Glock & Kunz, 2000) which may not be sufficiently flexible for changing cuff styles or for cuff feature customization. The primary technological developments which caused automation and mechanization can be named as motor and control electronics which will be discussed in the next paragraph.

2.1.2.2.2.2 Motor and Control Electronic Technology Evolution for Apparel Assembly

Motor and control electronics technology not only helped the process of automation and mechanization but also helped to gain flexibility and control to a greater extent thus benefits the mass-customized apparel manufacturing.

Technologies that have helped for automation and mechanization in apparel assembly can be summarized as:

1. State of the art electronically controlled alternating current (AC) or direct current (DC) servomotors (motor technology) are used to develop unique sewing programs in automating assembly operations.
2. Microprocessor based control electronics that typically use latest digital technologies, provide more flexibility and operator control over assembly operations and will be helpful for mass customization. Self-adopting equipment have been developed based on microprocessor technology using feed-back control to respond to the variable

conditions in the apparel assembly environment (Nilsson, 1983). Electronic controls give machines the capability of handling both information and materials. Electronic computer controlled machines are re-programmable in terms of stitch patterns, cycle times and operation of work aids. Electronic controls have introduced a new form of machine versatility that allows general-purpose machines to become semi-automatic with specific programmable processes. Also, special machines can now perform more functions and be more flexible through electronic control of sewing machines.

3. Digital technology allows the user to easily communicate to motor control electronics via standard digital communication protocols and will be unavoidable for flexibility.

4. Stepping motors (inexpensive, reliable, versatile, easily operated) replaced the cable and belt drive mechanisms used in mechanical systems (work aids such as pullers, elastic feeders). These motors can be programmed to move at precisely controlled speeds in both forward and backward directions allowing better process control in sewing operations. They can be used to control tension on fabrics when used with set speeds for various operations and can be used with photo-electric cells for edge guiding at the needle.

These technologies have provided capability to customize end user functions that are inevitable in customized apparel manufacturing. Servomotor is one half of the technology while the other half contains the control and power electronics which control the motor for various machine and sewing functions. The transition from clutch motors to AC or DC servomotors has not only improved the functionality and efficiency rating but also, reduced the operating cost in terms of energy usage (less heat generation, better work environment, saving on air conditioning cost, less noise level, improved operator comfort level). These modern electronic drive systems and controllers are activated in different ways such as foot switches, finger tip switches, leg pressure switches, etc. which provide flexibility for operator position at the machine. For example, stand-up sewing demanded by Modular stand-up units provide greater handling freedom and versatility, which makes it easier to switch between machines. The fingertip control switches provide the operator to lower or raise the machine top using a pneumatic mechanism (AAMA, 1992). The difficulty in using robots in apparel assembly automation is due to the non-rigid nature of fabric. Large amounts of information are needed to be fed back to the robot controller to render artificial sensory input and handling fabrics. This method is a difficult way to achieve economical human operator replacement. However, many developments have taken place through developing fully automated sewing systems. Also, in the future the long term needle-thread techniques may have to be changed and applications such as fabric welding and use of adhesives may need to be used. "Also, 3-D air jet or electromagnetic weaving may integrate textile and apparel manufacturing into one process" (Adams, 1993). These developments may assist the mass-customized apparel manufacturing in the future.

A traditional assembly operation can be divided into elements such as picking and placing, guiding, transferring, joining, repositioning and stacking. Considering these elements, apparel assembly automation/mechanization has been taking place over time with the productivity improvement as the primary motivation (Glock & Kunz, 2000). The reduction of assembly cost and the improvement of assembly quality come next in sequence. However, as the assembly systems with the elements described above move to use automatic or mechanized systems, the manufacturing systems will become less flexible with less human intervention. As mass-customized manufacturing needs high flexibility, the appropriate mix of elements that are automated or non-automated need to be appropriately selected. In mixed manufacturing, flexibility is a high priority. The task is to select these technologies to gain the required flexibility balance for the MP, MC mixed manufacturing process.

2.1.2.2.2.3 Pick and Place Technology

The pick and place technology systems are used to pick and place the cut fabric plies from a stack to be stitched. Research findings show that about 44% of a sewing machinist's time is used in positioning, re-aligning and presentation of work to the machine during the garment sewing process (Leung et al., 1992). "The success or failure of a particular system depends upon its ability to separate and pick up a single ply from a stack quickly and repetitively" (AAMA, 1992). Therefore, these systems help to improve the productivity thus shorten the leadtime. The sensors such as infrared, photo-electric and fiber optic are used for ply sensing for picking and placing mechanisms. Attempts were made to develop robots to function as pick, place and sewing devices. One such is the Singer's Manufacturer Applied Robotic Sewing system (MARS) (Anon., 1984). An electronic device can be used to sense the face side of the fabric which can be used in the separation process. Once the part is separated and picked it is transferred to the point of placement. The alignment of parts can be done with mechanical aligners, photocells (to detect the right position and send a signal to the micro controller), and micro controllers (send a signal to an electric valve to actuate a pneumatic cylinder to hold the part at the right position and drop on a conveyor to be advanced to the sewing position). “Extremely advanced fully automatic units have the intelligence to actually pick and place one part directly on top of a second piece and precisely align their corners” (AAMA, 1992). Some advanced automated systems are capable of feeding the cut parts from a stack completing multiple sewing tasks and delivering finished parts. Kalman (1998), AAMA (1988), Wong (1990)and Tait (1998) discuss applications of pick and place techniques (Kalman, 1998; Tait, 1998a, 1998b; Wong, 1990). Appropriate selection of pick and place technologies in the assembly operation may help the mass-customized manufacturing with sufficient flexibility and quality.

2.1.2.2.2.4 Guiding Technology

Operator can be assisted by guiding the material while sewing, using sewing machine attachments which are static or dynamic in nature. These allow improvements in the qualitative and quantitative output of the machine. Technology of edge-sensing which uses sensors such as photo-electric, infrared or fiber optic are commonly used as guiding mechanisms. These mechanisms can act alone to provide the guiding function or can be in combination with other mechanisms. The guide attachments are attached with a link or fixed to the sewing machine on the face, machine bed or the presser foot bar (Solinger, 1980). It is apparent that these mechanisms also use technology related to sensors, digital electronic controllers, switches, micro-processors and stepping motors. These technologies have provided many advantages such as improve speeds, improve product quality, ergonomics, operator safety and reduce visual and physical demand. Reduction in operator training and deskilling operators are further expectations (AAMA, 1991). Digital electronic technology allows the operator to easily communicate with the motor control electronics to carry out the assembly operation efficiently. With flexible adjustments, guiding technology will improve the leadtime and quality for mass-customized apparel manufacturing.

2.1.2.2.2.5 The Evolution of Sewing Machines and Sewing Mechanisms

In the discussion of mass-customized apparel manufacturing it is interesting to explore the evolution of sewing machines and sewing mechanisms over time. There are many questions about the primary inventor of the sewing machine. However, the following information is available in the literature about the evolution of the sewing machine.

- In 1755 Charles Weisenthal patented a double pointed needle to be used for mechanical sewing (Forsdyke, 2002).
- One of the claimants for inventor of the sewing machine in 1830 was Barthelemy Thimonnier, who patented a barbed needle, which was originally designed for embroidery but could be used as a potential sewing machine (The-great-idea-finder, 2002).
- The first working lockstitch machine was then developed by Walter Hunt in 1834 in America but was not successful as it could only produce short straight seams (DeWitt, 1994).

- In 1845 Elias Howe patented the lock stitch sewing machine (Forsdyke, 2002).
- In 1850s, the first practical, versatile and dependable sewing machine that sews straight or curved lines was developed by Issac Merritt Singer and the Singer sewing machine patented in 1851 was designed for factory use (Burns & Bryant, 2002). The chain stitch machine also was developed during this era.

From 1842 to 1857 more than 7000 patents were issued for sewing machines and accessories (Burns & Bryant, 2002). In 1880s, Singer Company introduced the zigzag and the electric machine for industrial use. Between 1900 and 1950s the basic machine design remained the same but more versatile and special purpose models were invented offering high speeds. Mechanical features for needle positioning and presser foot lifting were developed in the 1960s and were later enhanced with electronic technology. During the same time period, automated sewing systems which were equipped with electronic and optical technology were developed with under-bed trimming technology. In the 1970s the first electronic programmable machine came into use, which needed a new memory chip each time to change the programs. This development was further enhanced to have programmable special purpose stitches. A direct drive servomotor sewing machine came into existence during the same period. Highlights of technology developments in the 1980s include, advanced programmable machines which combine several operations to deskill operators and improve productivity, brushless alternate current (AC) servomotors and prototype special purpose robotic sewing systems. For example, the Textile and Clothing Technology Corporation $[TC]^2$ in corporation with Draper Labs carried out a project which employed image recognition and robotics to automatically sew men's coat sleeves. In the 1990s developments took place for automation to employ synchronized AC servomotors to drive separated upper and lower halves of the sewing head. A New generation of miniaturized, high speed, direct drive AC servomotors were available for the new sewing technology. Also, electronic coordination of servomotors were developed which allow having mechanically separated direct drive of needle and bobbin to eliminate all other shafts, gears and pulleys in the sewing head. With no mechanical linkage between the bobbin and the needle, these machines with, so called, electronic 'computer with a needle' claim that they eliminates 90% of the moving parts. By changing the bobbin and hook to a looper the machine could go from lockstitch to chainstitch" (Hasty, 1994). Adjustment of loopers, needle position, etc. was all done through the computer controls (Kalman, 1998). Because these machines were computer controlled, the capability of real time production or maintenance monitoring was possible. These characteristics are very important in mass-customized apparel manufacturing so as to be flexible for the feature changes as demanded by individual orders. In addition, potential for energy saving, noise and generation of heat reduction and ergonomic gains are other advantages of these electronic sewing machines. The eight year automated apparel factory project by MITI (Ministry of International Trade and Industry - Japan) used the apparel industry advances in robotic sleeve setting, fabric handling and feeding, tactile edge-sensing, automatic thread changing, automatic bobbin changing, etc. in developing the automated apparel factory (DeWitt, 1994). However, due to the limitation in flexibility, this fully automated apparel factory does not have required system needs for customized manufacturing of apparel.

2.1.2.2.2.6 Sewing/Joining Technology

Various technological developments related to joining of fabrics are discussed below. Some of these developments mainly address the productivity and quality improvement for MP but others can be used to achieve success in mass-customized apparel manufacturing that provide flexibility, quality and faster TPT. Sewing machines with memory banks or microprocessors allow the operator to perform an operation which can be repeatedly performed by the machine. Some of these actions are sewing given distances, raising and lowering the presser foot or repositioning during sewing and stopping and actuating a sewing line before and after repositioning. These machines with memory banks could have different control systems such as 'sew control' where only 'sew' and 'reposition' phases are automatic, 'sew and discard control' where 'sew, reposition, extract' and 'discard' are automatic and 'total operational control' where total operation is automatic from 'pick-up' through 'discard' (Glock & Kunz, 1990). Microprocessor controlled programmable needle positioning and other needle functions and stitch pattern regulating aid in forming a perfect line of stitches to facilitate programmable sewing, which offers versatility and increased sewing consistency (Solinger, 1980). Machines with multi-tasking heads provide better flexibility at the needle to facilitate different sewing on demand. For example, with electronically controlled needle thread take up and an indexable looper assembly/rotating hook assembly could make such machines possible (Early, 1994). From an ergonomic standpoint, sewing machines were developed to eliminate injuries caused by the conventional machines giving the operator more flexibility and more direct line of sight.

For example, a machine with a “differential top-feed that can be controlled quickly and precisely with the use of an external lever even when the machine is in motion” (Kalman, 1998).

Sewing machine cutting devices include thread cutters with or without wipers (to pull the remaining portion of thread when it is cut below the throat plate), chain cutters with latch back devices (to secure the initial segment of the chain at the beginning of the seam), tape cutters (may be with photo-cell sensors or stitch counters to cut neck bindings, shoulder reinforcements, etc.) and edge trimmers which include edge trimmers, under trimmers, seam cutters, and pinkers. The thread cutters range from manual devices to automatic systems. Foot operated thread cutting devices are activated by heeling back on the foot control and others are engaged by sensors (Solinger, 1980).

Advances in microelectronics and microprocessors have revolutionarized the sewing technology and work place design. Numeric control (NC) or computer numeric control (CNC) micro-processors, micro photo-electronic, fiber optic or infra-red sensors, stepping motors, AC (alternating current) or DC (direct current) servomotors are technologies that are used in modern assembly workstations. Advanced micro-processors (CNC) have the ability to sequence the task memory and synchronized processing in highly advanced automated systems. A simple software change can easily modify the system without a major hardware change. Modifications can be done by changing the E-Prom memory device on the control electronic circuit board (AAMA, 1992). Programmable logic controllers (PLC) are commonly used with programmable servo-motors which often meet all the programming requirements of an operation to integrate inputs and outputs into data control functions. The control electronics which uses digital technology are typically microprocessor based and allow the servomotor to direct the various machine and sewing functions such as needle positioning, presser foot positioning, backtacking, stitch counting, thread trimming and wiping, reverse feeding, tension releasing and bobbin thread detection which supports deskilling in combination with other technologies such as sensors. Infra-red and fiber optic sensing is commonly used to instruct the control electronics to automatically finish end of a seam sewing functions as stated above. Also, these sensors help the main technology to detect bobbin thread run-out and activate attachments such as the servo-motor, choppers, cutters and trimmers. These technological developments have helped the operator to improve the productivity and quality while deskilling the operation.

Sensors in combination with Pneumatics (using compressed air) have been used to save thread consumption and improve the seam quality. Start and stop signals from a sensor can be used to activate the pneumatic mechanism to suck the excess thread to be caught at the beginning of the seam, and to cut the thread at the end of the seam leaving a thread length which is sufficient to secure the seam. This mechanism will prevent the operator from continuously sewing between panels or garments, which will reduce the thread consumption (AAMA, 1992). Automated workstations (Escudero, 1995; Tait, 2001), machines with various bed shapes and rotating beds to stitch different material shapes (Kalman, 1998; Tait, 2001), automated stop motions and differential feed adjustment programs are some of the additional examples.

2.1.2.2.2.7 Intelligent Assembly Environments

Intelligent assembly environments have been developed which can determine systematically the properties of fabrics, predict effectively their sewability or tailorability, determine fit of certain criteria from the material properties on re-engineering, optimize the machine process settings efficiently and enable self learning from its own experience (Stylios, 1996). The features of such an environment are:

- A fabric measurement system to define the performance of fabric and its interaction with the machinery. Fabric properties and parameters can be transmitted to machines as barcodes.
- A sewability/tailorability prediction system to model the interaction of fabrics with sewing machines and to identify the difficulty during production and achievable quality.
- Intelligent sewing machines that can optimize mechanical adjustments of sewing thread controls and feeding foot pressure controls. These adjustments are done dynamically by motors using a fuzzy-neural model, based on properties of fabric and independently of any operational machine speed.
- Self-learning systems whose learning is based on the seam quality assessment criteria. With the comparison of measured details and the learned knowledge, signals are sent to the control model to alter or reinforce its control criteria (Stylios, 1996).

Using technologies such as fuzzy logic, neural networks and advanced sensing, the sewing motor controller can monitor operator's every move to learn and take over the skill sequence of the operator. If variations to the learning cycle are observed, it will alert the controller and will start the learning cycle again. If the operator reverts back to the old cycle after the cycle change, the controller will recognize it and will revert to earlier cycle (Early, 1994). Sewing machines have been developed with speech recognition capability. The speech recognition device can be a portable micro-computer with speech processing and synthesis. Using the pre-programmed verbal commands, the unit recognizes the operator's commands from a microphone. Once the unit recognizes the correct command, it sends a combination of signals to an Efka electronic motor that, in turn drives the sewing machine (Rowland, 1992). Clemson Apparel Research has been able to perform any of its dress shirt operations utilizing six commands. These intelligent assembly systems can be very expensive, but if appropriately adopted, they can be used in mass-customized apparel manufacturing as the earnings from customized apparel are comparatively higher compared to MP of apparel.

2.1.2.2.2.8 Fully Automatic Assembly Systems

Automatic systems are classified as capable of carrying out a single function or a combination of functions without the direct participation of an individual. The input material or in-feed magazines must be filled, the finished stacker canisters must be emptied, and problems such as thread-breaks must be attended by an operator. A single operator controls several machines thus signaling devices are equipped with machines to get the operators attention when a problem arises. The fully automatic machines equipped with user-friendly controls, which are capable of auto-diagnostics, further aid the operator to react to problems fast (Glock & Kunz, 1990). Some of these mechanisms (for example, automatic button attaching and serging) can be used for mass-customized apparel by carefully selecting the suitable system for a specific customization approach.

A major research project to automate the complete garment manufacturing system was conducted by the Technology Research Association of Automated Sewing Systems (TRASS) in Japan. The aim was to set up various technologies necessary for an automated sewing system, which efficiently makes apparel in small lots and wide variety at small and medium size clothing firms. The total system consisted of preparatory sewing technology, sewing and assembly technology, fabric handling technology and system management and control technology. The main aim was to shorten the per-piece manufacturing time. The research and development of the test plant was carried out in 1988 with the manufacturing of ladies blazers. Interlining attachment, part transportation, positioning, recognition, inspection, panel matching, seam opening and pressing and stitching are some of the automated processes for blazers. Also, automatic 3-D stitching was developed in the assembly system (TRASS, n. d.). Recent literature on robotic stitching technology discusses high accuracy, numerically control industrial robots that are used to carry specially designed stitching heads, along the seam paths. One such application of this unique three-dimensional stitching techniques is in 3-D textile structural composite production. For this technology a one-sided stitching system has been used with two stitching tools which has the simple chain stitch formation mechanism. This stitching technique is a new development for this type of applications (Wittig, 2001). Some examples of fully automatic work stations are discussed by Kalman (1998) and Tait (2001).

2.1.2.2.2.9 Linking/Combining to Achieve Manufacturing System Needs

The idea of linking or combining operations is to satisfy the manufacturing system needs such as increase productivity, quality and improve the TPT. However, the flexibility can be affected due to this approach. This technique has been used by most apparel technology developers in mechanization and automation of workstations. For example, effort has been made to automate and combine the basic functions in a sewing workstation such as pick & place, guide, join, reposition and stack. The development of digital electronic control technology has allowed the sewing machine's motor control electronics to be easily connected to the outside user through communication ports to operate these linked operations. For example, linking the functions such as edge-guiding, backtacking, needle positioning, presser foot positioning, thread cutting, stitch counting and operating an external stacker with supportive technologies such as sensors. These new technologies have helped to link and combine previously existed "islands of automation". Automation of sewing operations with enhanced data communication standards has allowed one machine to send data to another to automatically complete tasks. This was possible with the development of electronic communication protocols so that different machine manufacturers could link their machines to a single system. Automating and linking the turning, pressing and topstitching of shirt cuffs is an example illustrates in the literature (AAMA, 1992).

Combining of operations leads to deskilling and provides the ability to operate a 'machine gang.' The idea is that a single operator will operate more than one machine. The combination of mechanics and electronics ("mechatronics") has provided the independent movement of material between linked operations. Combined sleeve operations (AAMA, 1992), combined seam stitching and seam opening (Lindley, 1993), combined vacuum head material pick-up, placement and automatic stitching or fusing (Wong, 1990), combined automatic pocket operations (Tait, 1998a) and combined programmable eyelet button hole functions (Tait, 2001) are a few examples, which illustrate this concept. As flexibility is an important need in mass-customized apparel manufacturing, it is applicable to have elements of operation in isolation than combination which needs customization. However, based on what points need customization this strategy can still be applied to other non-customized operations within the mass-customized manufacturing system.

2.1.2.2.2.10 Deskilling as a Method to Achieve Manufacturing System Needs

The apparel industry is a highly labor intensive industry and requires high levels of operator skills. As many simple and complex work functions are involved in an apparel assembly operation, it has become extremely difficult for the industry to secure a sufficiently skilled work force necessary for the manufacture of products, which are of consistent quality. Therefore, various technological developments have evolved over time to deskill apparel assembly operations. Manufacturers have used these technological developments to set up more responsive sewing units with least amount of operator intervention to reduce waste and to improve the assembly quality. Some of these advanced technologies provide a reduction in mental, physical and visual demand from the operators, e.g. guiding sensors reduce mental and visual demand and deskill the operator.

Sewing machine attachments or work aids are mechanisms that help to deskill operations and guide, position or prepare the material for the sewing operation at the machine or make the future operation ready for the future process. Guide attachments enable the operator to guide fabric correctly and quickly while fabric manipulators move or bend the fabric during the operation. Folders, hemmers and fellers are examples for manipulators.

With the ability to change programs rapidly using electronic technology, different sizes can be accommodated instantaneously. This is an important need in manufacturing size variety for MC. Some of these machines with this programmability require almost no operator sewing skill except for the ability to adjust thread tension, wind and load bobbins, and thread the needle. In fact, the placement of the pieces is dictated by the work holder itself in most cases (AAMA, 1992). Applications such as attaching labels, stitching different box tacks and eyelets, attaching velcro, pleating and tacking pants, attaching buckles, stitching seat belts, air bags, logos and emblems are a few examples.

The manual apparel assembly operations can be split into two areas; automated operator functions and manual operator functions. Microprocessors with programmable read-only memories (PROMS) have taken over a considerable part of both routine and skilled manual operations. There are still a considerable amount of sewing operations, which are so complicated that they do not allow for easy automation. The application of mechatronics has further helped in deskilling the operations (Taylor, 1990). Literature provides many examples in relation to deskilling such as,

- full-fell seaming introduced to deskill the difficult leg seaming operation in manufacturing denim jeans (Tait, 1998a).
- detecting consistency in label dimensions and placement for sewing (Kalman, 1998).
- automatic bobbin changing and winding (Anon., 1995).
- metering devices to control cutters, stackers and other devices used for sewing and programmable stitch pattern selection for zigzag machines (Kalman, 1998).
- detect and provide required amount of thread in the seams (seam elongation even up to 190%) of stretchable fabrics (Tait, 2001).

2.1.2.2.2.11 Material Handling to Achieve System Needs

Maintaining quality, fastest turn-round, space, maximum reduction in standard minutes, high productivity, a clean and attractive environment for the operators as well as to impress the customers and lowest WIP are important requirements that are considered in material handling in an apparel plant (Tait, 1992). The handling system can become complex in mass-customized manufacturing with the varying extent of customization. Based on the research carried out on material handling in the garment industry, it has been found that 50% of the cost of a garment is incurred in manufacturing and 20% of this is labor cost. Activities related to handling materials mainly account for this labor cost. Also, it is expected that 47% of garment manufacturing can be carried out by robotic methods or automation (Leung et al., 1992). However, it is important to understand the inherent characteristics of fabrics before a handling technique is selected.

Handling cost can be reduced by eliminating as much handling as possible and reducing the distance that the materials are moved. Material handling does not add value to the product, but it affects workflow and productivity. A well planned and efficiently used material handling systems can decrease TPT, minimize handling and operator fatigue and improve control of WIP. Handling of materials at an assembly workstation depends on how parts are presented to the operator, the degree of automation and the disposal system used. Material handling procedures are usually incorporated in the production method for each operation, which is an important element of the work function, as it accounts for about 80% of a sewing operation time (Glock & Kunz, 2000).

With mass-customized manufacturing, simultaneous handling of different production processes and parallel channeling of styles is often required to achieve flexibility. Handling systems range from simple work aids and attachments such as slanted tables, folders, fellers and binders up to complex mechanical, electronic and computerized unit production systems (UPS) and automated guided vehicles (AGV) (Aldrich, 1995; Tait, 1992). Further, material movement by individual operators is used with systems such as TSS. As discussed under manufacturing systems, different systems use different material handling techniques to achieve various tasks. Out of these many systems, mechanized conveyor and automated overhead conveyor systems help to reduce the handling component of the assembly function which can transfer the handling to sewing ratio from 80/20% up to 60/40% (Tait, 1992).

UPS is known to have one of the best automated material handling system. This can be one of the reasons that mass-customized manufacturing prefer UPS. Another reason may be the inherent garment tracking. Some UPS systems can have delivery systems, comprised of an interlocking adjustable chain, allowing to deliver the hangers to the workstation at variable heights for ergonomics concerns. Systems allow data collection and management reporting, computer assisted routing, line management controlling functions and planning which relies on bar code readers to obtain work information. Based on a case study by Little and Carrere (1986), the Table 2.7 shows a comparison of PBS and UPS material handling information with regard to three operations and their material handling technology, which illustrate the extent of savings that can be achieved with such a system. This dissertation research considers these two systems in mixing MP and MC apparel manufacturing.

Table .2.7: Comparison of material handling times for operations (Minutes per piece)

Operation	Bundle System	UPS	Material Handling Savings
Join shoulders, set under collar, sleeves, side pockets etc	1.797	1.217	34.98%
Seam sash, overlock undercollar, bottom and attach label	0.601	0.391	32.27%
Blindstitch cuffs fronts, hem and undercollar	0.585	0.405	30.82%
		Average	32.56%

In a UPS headline system the hangers can be accumulated at individual workstations. A closed loop configuration will allow hangers to by pass workstations routing to the desired workstation.

Edge de-curling devices to handle fine fabrics (Tait, 2001), simultaneous multi-style capable UPS such as “Gerber Mover”, “Investmove” and “Eton” (Tait, 1992), manual, powered or combined mono rail systems such as “Tectrac”, manual rail systems such as “Switchtrack” and “Quicktrack” and twill rail systems such as “Vario Flow”

(Tait, 1992) are some of the examples that are illustrated in the literature for effective material handling. ETON now dominates the North American market following a merger with the “Gerber Move”.

2.1.3 Apparel Manufacturing Supporting Technologies vs. Assembly Technology

The existing apparel manufacturing systems, assembly technologies, their developments and other strategies to achieve various needs were discussed. The discussion 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 system expectations. 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.

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 and the average number of patents issued for each year since 1971 up to 2002 are graphically represented in Figure 2.5.

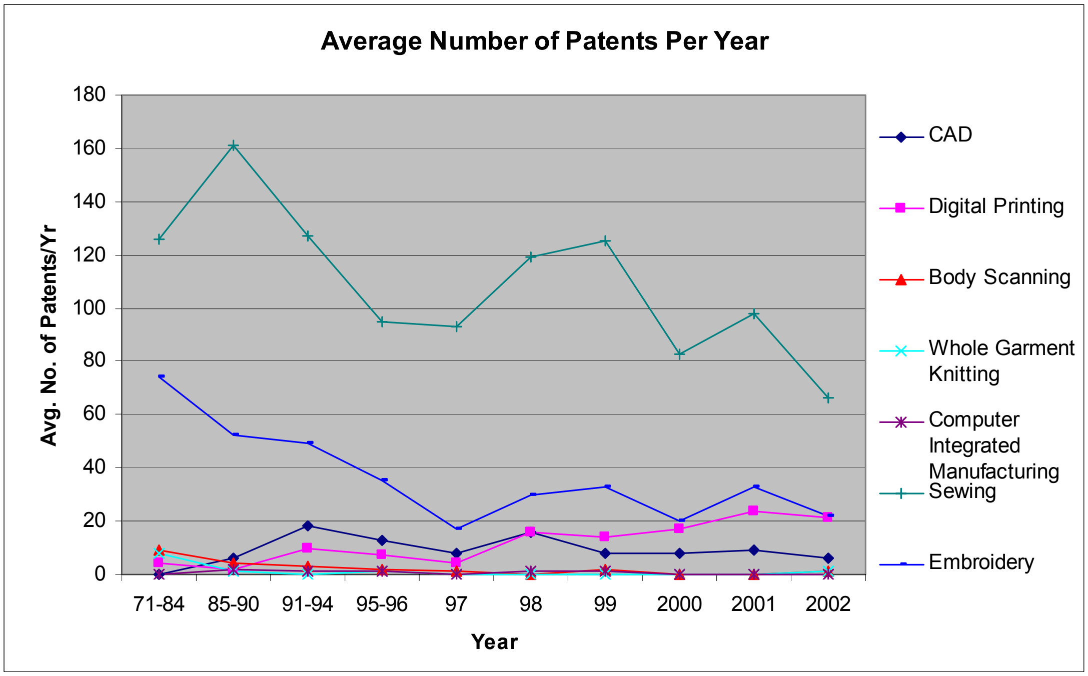

Figure 2.5: Sewing and supporting technology patents issued per year (U.S.Patents, n. d.)

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.

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 mass-customized apparel manufacturing. 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 mass customization. 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 dissertation 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 mass-customization 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

PBU compared to movement of product through many operations in a short time period in a UPS. 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 mixed 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. 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"[1] (Senanayake & Little, 2001). The evolution of the Internet has provided the means for sharing technical/product information among the apparel manufacturing systems. With a universal, low-cost, high-performance network it has transformed how companies

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[1] See Chapter 3: Measures for New Product Development

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. 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[1] for mass-customized apparel manufacturing practice. 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 mass customization using the CAD technologies with automatic pattern alteration systems.

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[1] See Chapter 4: Points of Customization

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 mass-customized apparel manufacturing that can even achieve higher end Design Customization[1].

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[1]. The made-to-measure apparel requires underlying technology to facilitate acquiring human body measurements and extracting appropriate critical

[1] See Chapter 4: Point of Customization

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 mass-customized apparel manufacturing to a greater extent[1].

2.1.4 Summary of Manufacturing Systems and Technologies

The summary of assembly and supporting technology infrastructure in the apparel industry is graphically represented as shown in Figure 2.6. The literature reviewed was used to develop a comprehensive system attribute comparison table which is helpful in identifying the requirement in researching mixed MP and mass-customized apparel manufactuing system[2]. It was found that the development of various technologies 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

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[1] See Chapter 6: Personal Communication
[2] See Chapter 6: Research Findings, Results and Discussion

technology developments emerging at a rate of about 117 per year which includes both sewing and supporting technologies. 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. The goal of the literature review on MP assembly systems, available technologies and supporting technologies was to identify what is available today to manufacture apparel and how these can be used to research mixed MP and MC manufacturing that can be used for both MP and MC apparel manufacturing. The next section will address transition into mass-customized manufacturing and will discuss in detail the literature available for mass customization.

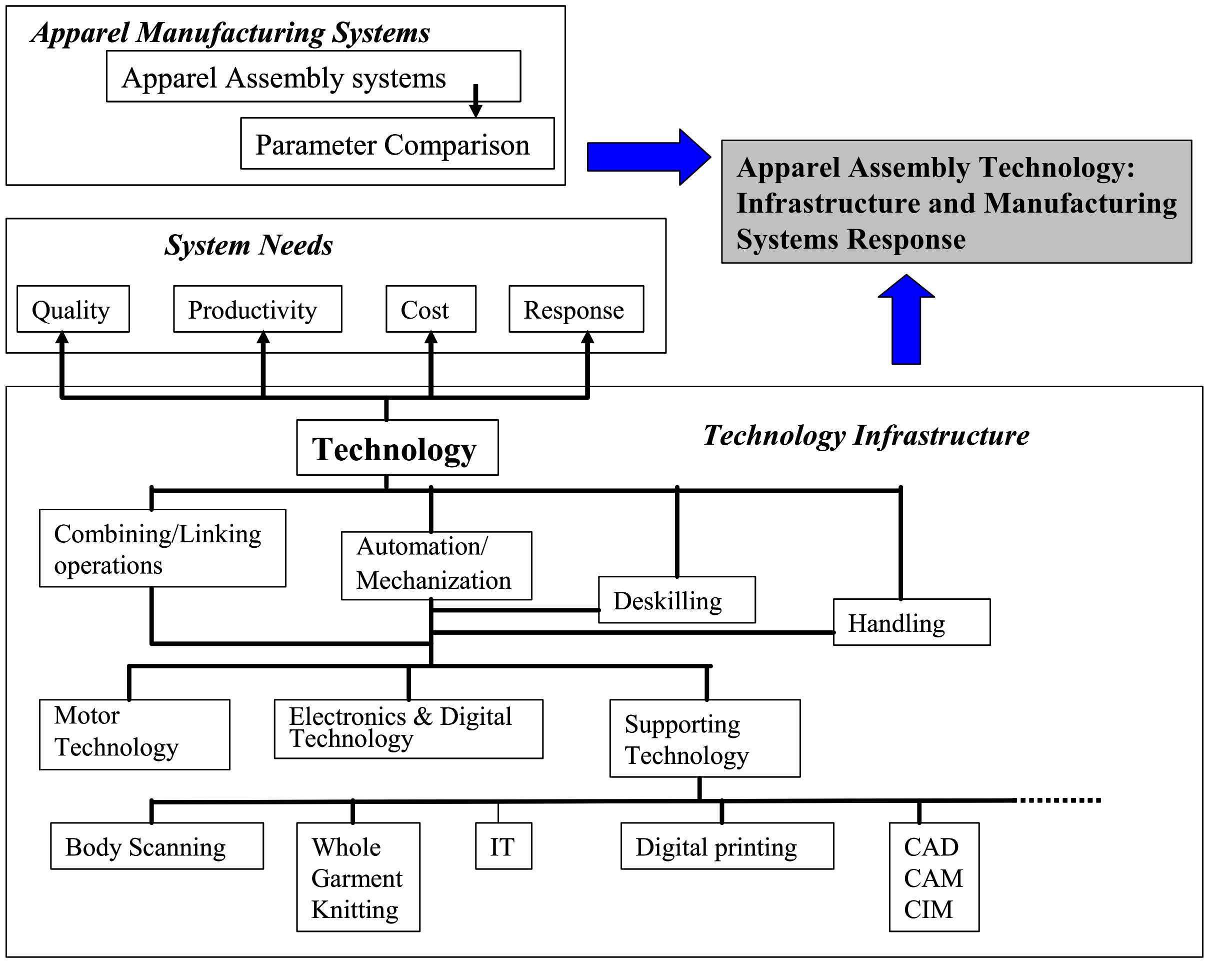

Figure 2.6: Understanding apparel assembly technology, infrastructure and system response

2.2 MANUFACTURING FOR MASS-CUSTOMIZATION

Available literature was scarce that identifies the research proposal of mixed MP, mass-customization (MC) apparel manufacturing. The following section will identify the literature available that discusses manufacturing for MC. Important studies of manufacturing in strategy by Woodward (1958, 1965) in seminal studies of British firms can be traced back which explains that production technology has systematic relationship with the organizational structure and the management characteristics of a firm (Woodward, 1958, 1965). Out of nine different categories of proposed framework by Woodward (1965), four categories; "job shop", "small batch", "assembly line", and "continuous flow" were discussed explicitly by Hayes and Wheelwright (1979). Hayes and Wheelwright (1979) proposed a dynamic framework for matching firm's product and market evolution with manufacturing process characteristics, arguing that a customized (one-of-kind) product was best produced in a job shop environment whereas a standardized product was best produced in an assembly line mass production environment. Their rationale for matching products with process characteristics was based on economies of scale and the intensive capital investment required to manufacture products in large volumes. That is, their framework illustrated a tradeoff between product variety and production cost. From a strategic standpoint, this trade-off involved setting increased efficiency with lower unit cost, higher precision, and high product volume against flexibility (Hayes & Wheelwright, 1979). In contrast to traditional systems based on economies of scale, the new thinking for economies of production are based on the concept of ‘economies of scope’ (Goldhar & Jelinek, 1983) and substitution (Garud & Kumaraswamy, 1995).

Staples (2001) discusses a concept of ‘Paired Production” as a roadmap for the US apparel manufactures to gain competitive advantage. This is a combination of high velocity and low velocity manufacturing for producing stock items for mass customization and the idea has been demonstrated with the following graph.

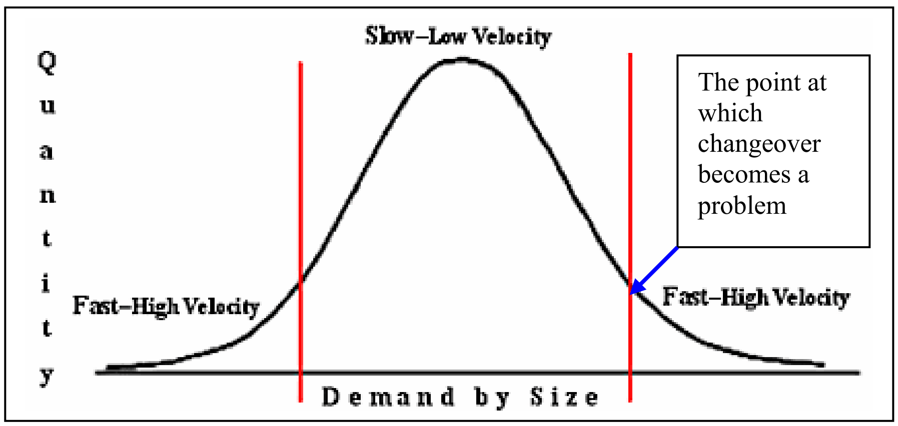

Figure 2.7: Concept of paired production (Staples, 2001)

The sizes that can be expected to make in large quantities are in the center, which represent low velocity, low cost production and the few sizes in the tails of the normal curve represent the high velocity higher cost production. The paper discusses the steps to move in to the paired production mode and identify the point at which change over from high velocity to low velocity occur as a key factor. A major task is being identified as implementing a high velocity manufacturing line. The initial focus for the line is to manufacture non-replenishable SKUs that have frequent changeovers of sizes and quantities. Gradually it can be developed to incorporate low-replenishable SKU’s of needed quantities. The manufacturing can be domestic or a mixture of domestic and off shore. With an efficient high velocity line it is possible to move beyond stock items to explore MC. The manufacturer can produce apparel for MC by supplying minor changes to stock items such as changing shirtsleeve length as required by customer and by offering limited choice in features and fabrics. Size, style and fabrication are the MC parameters that interests to the consumer (Staples, 2001).

The motivation to mass customize will lie in finding efficiencies in two key dimensions; to include each customer's specifications in the product design and to utilize a modular design to achieve manufacturing efficiencies closer to MP efficiencies (Duray, Ward, Milligan, & Berry, 2000). Comparing MC and 'customer driven manufacturing', literature suggests that customer driven manufacturing originates from traditional manufacturing paradigm, 'one-of-a-kind production' and MC originates from MP paradigm (Tseng & Piller, 2003). The following Table 2.8 provides a comparison of MC and customer driven manufacturing.

Table 2.8: MC vs. "customer driven manufacturing" (Tseng & Piller, 2003)

	Mass Customization	Customer Driven Manufacturing
Complexity of product	Low (usually commodities)	High (usually capital goods)
Level of customization of product	Low to medium (often restricted to limited variety of configuration/product types)	High to very high (what the customer wants is what he gets)
Integration of customer into order processing	Usually low	Usually high (often fully integrated)
Type of customer addressed	Usually consumer	Usually suppliers, service providers etc

The MP, one-of-a-kind production and MC is considered in the view of stability of the process and variety of product as described in the Figure 2.8.

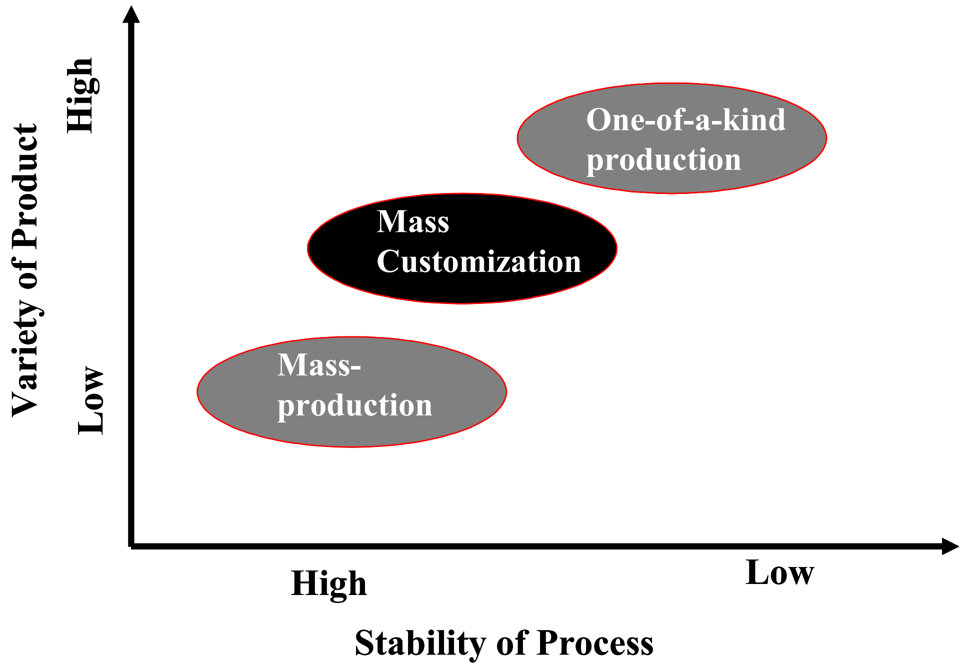

Figure 2.8: Product variety vs. process stability (Tseng & Piller, 2003)

MP is characterized by high process stability (with no changes or modifications during the order processing) and low product variety. Product specifications and process specifications are changed from order to order in one-of-a-kind production thus low process stability in high product variety. To achieve cost efficiency, MC needs stability of the process but to cater for high product variety. This is the challenge that is placed upon the modern manufacturing and other technologies. Considering the already discussed manufacturing systems, author suggests that bundle system can be related to MP and make through system for one-of-a-kind production. Modular and UPS can be recommendations for MC. As shown in Figure 2.27, the literature discusses that the main focus of MC so far is on ATO (assemble-to-order) and MTO (make-to-order) but ETO (engineer-to-order) approach is not practiced much and if implemented, it may be restricted to the customer driven variation of single and predefined product features (Tseng & Piller, 2003). In case of apparel MC this is slight different as the industry practice shows[1] that the spectrum of customization spreads across made-to-stock and engineer to order customization.

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). The above explained operation for Motorola pagers can be used as an operational strategy for mass-customized apparel manufacturing. 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

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[1] See Chapter 6: Survey Analysis

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). With the idea of manufacturing requirements, the next section will provide a detailed overview of apparel MC.

2.3 MASS-CUSTOMIZATION

2.3.1 Mass-Customization: Definitions 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 2.9, that is the reverse of the model explained under the heading of Mass Production.

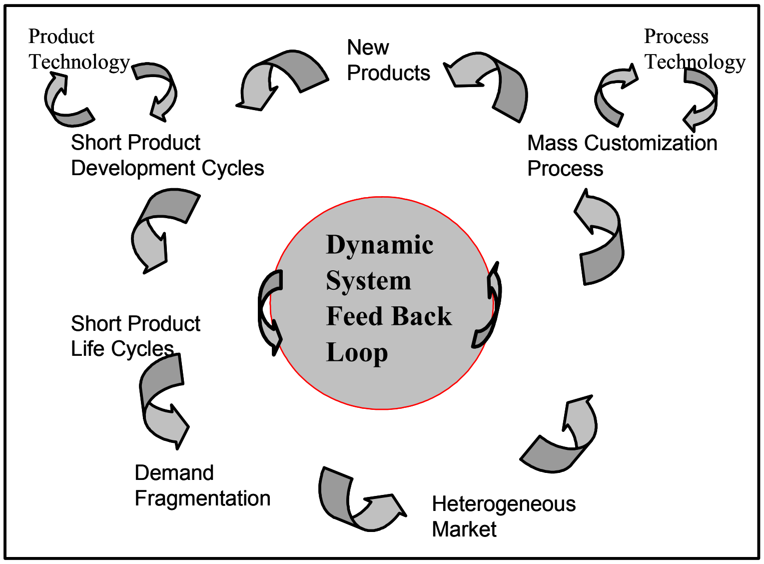


Figure 2.9: The new paradigm of MC as a dynamic system feedback loop (Pine-II, 1999)

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 2.10. They discuss technologies such as 'smart card', 'body scanning', and information collection and transfer as examples in apparel industry.

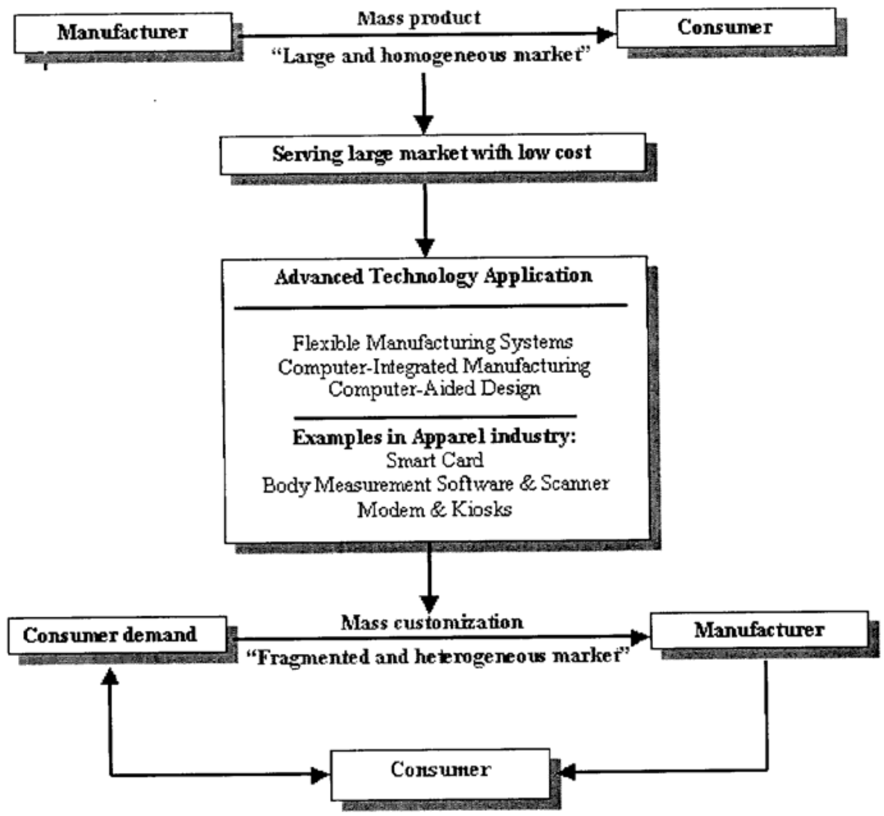


Figure 2.10: Concept of mass customization (Lee & Chen, 1999)

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 mass-customization have created new expectations in the marketplace and new demands for manufacturers. Manufacturers of configurable products must rapidly transition to a mass-customization 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[1] 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 author believes that apparel MC is manufacturing apparel for individual customer demand and personalizing it for the preference of the customer. In addition, the emphasis is that individually customized apparel need to be

[1] See Chapter 2: MC tools and techniques

manufactured using a "mass production approach" to gain the cost benefits obtained by MP of apparel.

2.3.2 Enablers of 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". Therefore, the previously discussed production systems may need to be changed or modified to cater for the product and process technology demanded by the MC. 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. As customers demand customized products, a greater need arises to re-engineer processes for MC. The production system may need to be equipped with 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.

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.

The QR and JIT strategies changed the management of human resources, equipment and materials in the industry, but continued businesses' traditional focus on improving efficiencies and quality, reducing costs and shortening leadtimes rather than shifting the focus to the 'right product for the consumer' which is the aim of MC.

It is important to understand the extent and the continuum of mass customization that can be realized by the available manufacturing systems. MC may efficiently build families of synergistic products, but may not be able to build all products. Further, it is important to identify the product family architecture that can be customized based on a combination of market needs and organizational capabilities. An optimal grouping of products into product families that can be built efficiently on demand without setup delays and with all the parts and materials always available is a key requirement for MC manufacturing. It is also required to eliminate the most unusual products from the mass customization program by strategies such as product line rationalization (Anderson, 2003). According to Anderson (2004), "it is important to remember that mass customization operations can customize a certain range of products very efficiently, but just outside that range it may be difficult and beyond that it may not be feasible at all". In addition, it must be understood that all customization offerings may not be equally and well received by the market place. For example, it is required to identify whether consumers are more interested in standard sizes with many available options or apparel made especially for their sizes based on the type of apparel. It is important to make sure that the MC orders will not exceed the capability of the manufacturing system thus sales and marketing will not provide unrealistic expectations for the customers. Being able to build products in batch size of one as a flow in MC, it will facilitate improved quality, low work-in-process, quick throughput, reduce floor space and low overhead costs (Anderson, 2004).

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. This is also one of the objectives in this research.

An 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. 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 (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 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.

2.3.3 Benefits of Mass-Customization

The driving force in MC is the potential benefits of MC compared to the existing system of MP. Improved fit with each customer's unique needs will help to satisfy the customers and increase customer loyalty. For example, "the repurchase rate for Levi's Personal Pair custom fit jeans was 38 percent as opposed to 12 percent for its traditional jeans" (Berman, 2002). The ability to maintain lower inventory levels throughout the supply chain helps in improved profits by means of reduced markdowns and interest costs, improved cash flows, effective space utilization, etc. Customers are motivated to buy customized products at a higher price because primarily it is customized and the product needs no modifications such as alterations after purchase. The continuous and direct dialogue between the mass customizer and customer help to provide the right product to the consumer. As an added advantage, this information can be used to develop new mass products for customer preferences (Berman, 2002). The cost and economic advantages of apparel MC is discussed in detail in the next paragraph.

2.3.3.1.1 Cost and Economic Advantage of Mass-Customization

The economic advantage of MC is the driving factor in a successful MC business. Anderson (2003) addresses the concept of cost of variety, which is a closer look at the current attempt to practice manufacturing variety of a single product. He refers to this cost of variety which is applicable to many companies today as the "sum of all the costs of attempting to offer customers variety with inflexible products that are produced in inflexible factories and sold through inflexible channels". As he discusses the costs that must be considered in identifying the manufacturing variety are, customizing and configuring product costs, setup costs, costs of excessive parts, procedures and processes and excessive operations costs caused by meeting variety from inflexible systems. A different approach for obtaining this cost is to compare the company's current operating budget under the idealistic situation of producing a single product with no variety to a mass-customized product with similar volume using a similar manufacturing process. The difference between the current operation cost and the single product scenario calculates the variety cost.

Figure 2.11 from the book, "Build to order & Mass customization" by Anderson (2004) shows a pictorial representation of the concept of market variety and cost of variety. Increasing market variety causes the variety cost of MP to increase exponentially because of the cumulative effects of inefficiencies faced by MP manufacturing practices. Similarly, Figure 2.12 shows how response difficulty changes with market volatility in case of MP and MC. The response difficulty for MP rises exponentially with increasing market volatility. Considering apparel MP and MC, this representation shows a practice of MP in a market environment with changing demands for manufacturing variety of styles. As Anderson (2004) shows the MC practice will be able to overcome both the variety cost and response difficulty issue because of eliminating setup, reducing batch size, eliminating or reducing WIP, improving customer loyalty, etc. It should be noted that these graphs are qualitative rather than quantitative.

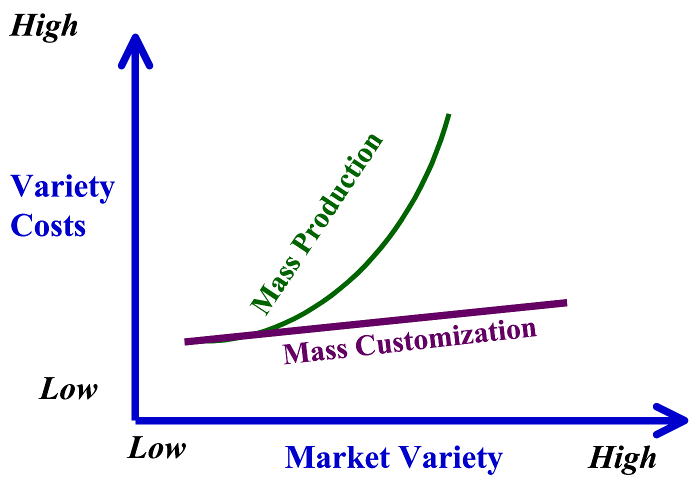


Figure 2.11: Graphical representation of "variety costs" vs. "market variety" for MP & MC (Anderson, 2004)

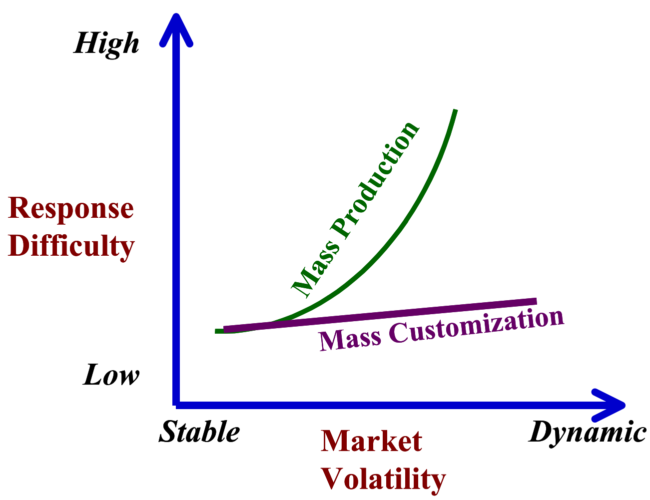
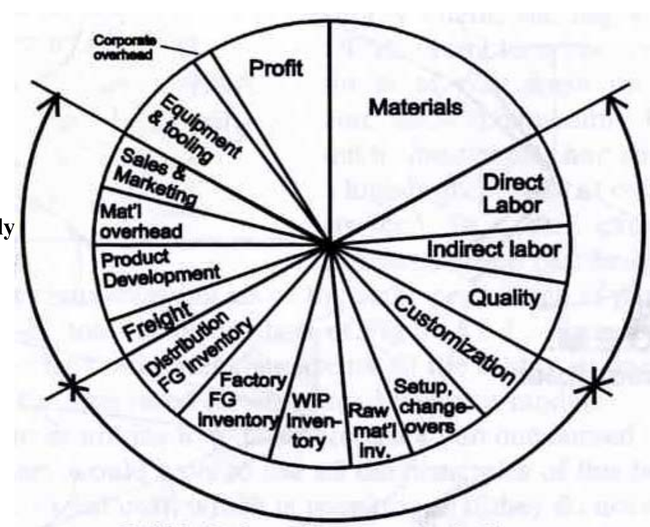


Figure 2.12: Graphical representation of "response difficulty vs. "market volatility" for MP & MC (Anderson, 2004)

As Anderson (2003) argues the efficient practice of Build-to-Order and mass-customization can lower many costs even to a point below that of most of companies' current MP costs. To realize this argument, the cost must be calculated with the total cost approach. Figure 2.13 shows elements of costs involved and strategies to minimize them considering the Build-to-Order and MC approach (Anderson, 2004). The design for manufacturability (DFM) and lean production efficiencies can minimize the direct/indirect labor costs and quality costs. Standardization and product family synergies help in lowering the material overhead, product development, marketing and shipping costs. The techniques used in MC with on-demand lean production may virtually eliminate or reduce setup changeover costs, customization costs and inventory costs (both at the factory and in distribution channels). It is important to explore the validity of this concept for mixed MP, MC manufacturing with respect to apparel. In addition to the above cost advantages, companies that practice MC of apparel have other financial advantages such as fewer returns, markdowns, and close-outs, and cash flow benefits with sales revenue is collected at the time of the order placement.



Reduced by standardization and product family synergies

Reduced by DFM and lean production efficiencies

Build-to-Order and mass customization can virtually eliminate these costs

Figure 2.13: Total cost minimization strategy (Anderson, 2003)

A business analysis conducted by Kurt Salmon Associates (KSA) for the Textile Clothing Technology Corporation [TC]^2 compared the profitability for both the retailer and manufacturer under traditional domestic manufacturing, traditional off-shore manufacturing (807), and domestic mass customization. KSA studied these situations for a typical basic garment, a typical seasonal garment, and a typical fashion garment (Kurt-Salmon-Associates, 1997a). The information for a basic typical garment is shown in the Figure 2.14. A similar pattern of information was observed for the seasonal and fashion garment.

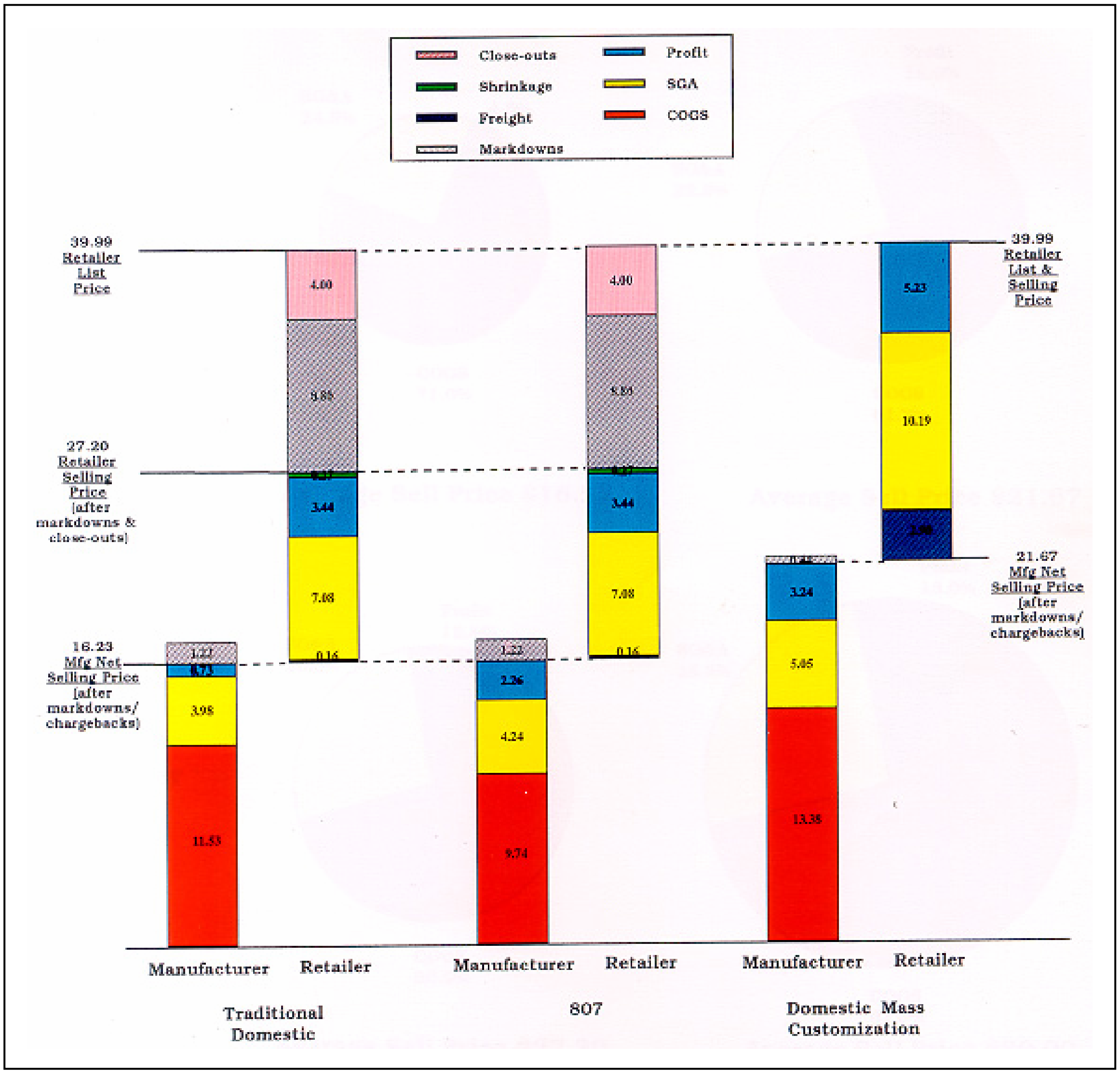


Figure 2.14: Cost and profit comparison for a typical basic garment (Kurt-Salmon-Associates, 1997) (included with permission from [TC] ^{2})

When the manufacturer is concerned the domestic MC has a higher manufacturing cost (cost of goods sold - COGS) as well as higher Service, General and Administrative (SG&A) overhead costs compared to both the traditional domestic and 807. But the MC manufacturer can earn more profits. Reviewing the information for retailers, higher costs for freight and SG&A overheads incur for MC. But the profit margin is still higher and due to the fact that there are no markdowns and close-outs, MC business earnings are higher. Furthermore, as MC can further add a premium price for the service without loosing the market, the profit will be very much higher than the traditional business. This argument is realistic because according to [TC]^2, results from KSA's 1997 Consumer Out Look Survey has shown that about 36% percent of consumers are willing to pay 12-15% more for custom made apparel and footwear. Considering previous research and current state-of–the–art, I propose that for mixed MP and MC manufacturing, the COGS and the SG&A overheads can be lowered by using Radio Frequency Identification (RFID) for better order tracking of MC orders.

Information as shown in the Table 2.9 is adopted from the business analysis report (Kurt-Salmon-Associates, 1997b)and shows the comparison of percentage COGS, percentage SG&A, and percentage profits based on selling price and average selling prices for manufacturers and retailers in case of traditional domestic MP and domestic MC. The difference of MC and MP (MC-MP)for these values as shown in the last column describes a similar pattern for all three types of garments concerned. The domestic MC has lower percentage COGS, lower percentage SG&A and higher profits.

The cost benefits from MC can be enjoyed by manufacturers, retailers and consumers. Reducing markdowns and charge-backs generate better financial results for the retailers and manufacturers. Establishing flexible manufacturing system to cater for the changing market place will provide the continuing ability to gain competitive advantage. Retailers can avoid potential lost sales and markdown opportunities and can obtain better financial results. Most importantly, the consumer will benefit by having the product that is needed at the right time.

Table 2.9: Costs, profits and selling price comparison. Adopted from KSA report (1997)

	Traditional Domestic		Domestic MC		Change MC - MP	
	Manufacturer	Retailer	Manufacturer	Retailer	Manufacturer	Retailer
	Typical Basic Garment					
COGS %	71	60.9	61.7	61.5	-9.3	0.6
SG&A %	24.5	26.3	23.3	25.5	-1.2	-0.8
Profit %	4.5	12.8	15	13	10.5	0.2
Avg Sell Price	$16.23	$27.20	$21.67	$39.99		
	Typical seasonal garment					
COGS %	54.3	62.7	44.5	63	-9.8	0.3
SG&A %	24.5	26.3	23.3	25.5	-1.2	-0.8
Profit %	21.2	11	32.2	11.5	11	0.5
Avg Sell Price	$17.05	$27.71	$23.57	$41.99		
	Typical fashion garment					
COGS %	57.4	64.7	44.9	64.9	-12.5	0.2
SG&A %	25.7	26.3	24.4	25.4	-1.3	-0.9
Profit %	16.9	9	30.7	9.7	13.8	0.7
Avg Sell Price $	$17.86	$28.15	$25.64	$43.99		

The paper, "Adoption of Internet-Based Product Customization and Pricing Strategies" (Dewan, Bing, & Seidmann, 2000) discusses the comparison of seller's costs and profits that sells standard products and customized products. It compares three scenarios of two sellers adopting customized or standard product sales. The paper uses a mathematical model that considers the additional cost of customization as the length of an arc of a circle. The points of this circle represent consumers most preferred products and when a firm adopts customization and produces a range of products, they are represented as an arc of the circle. This additional cost of customization is represented as $ax^2 + bx$, where x is called the firm's "customization scope" and is the length of the arc over which the firm produces the customized products. The customization scope measures the firm's manufacturing flexibility. The quadratic term (ax^2) is referred as the "diseconomies of scope" and reflects the decreasing returns in manufacturing flexibility investment. The linear term (bx) of the customization cost function simulates the constant returns to scale in buyer information processing. As shown in Figure 2.15, the paper considers three scenarios and based on the model the following results have been discovered.

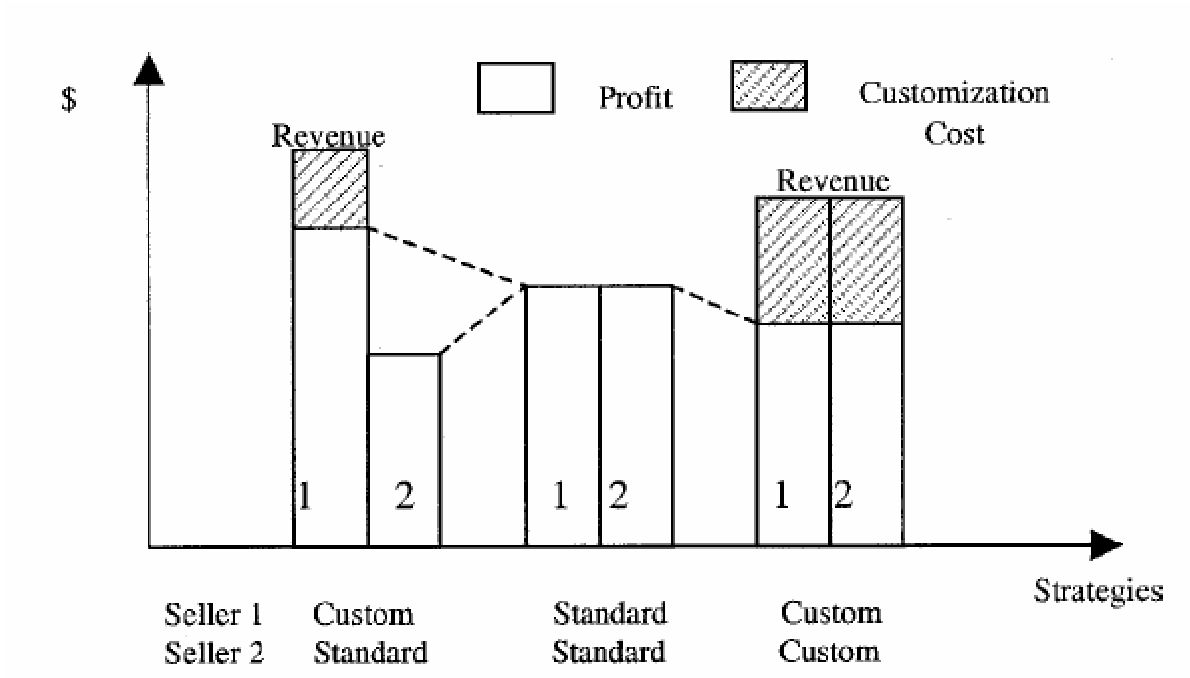


Figure 2.15: Sellers profits and costs under different cases for competitive strategy (Dewan et al, 2000)

The results of this paper have shown that an early adopter of internet technologies for product customization can sell and charge more for tailored products, achieving an advantage over the peer conventional sellers. According to Dewan et. al (2000), when there are two sellers, both who sell customized products, will earn lower profits compared to both who sell standard products. The profits, however, will be higher than one who practices standard product sales in a market that has another seller who sells customized products. In addition, the paper explains that the seller adopting customization can raise the price for his standard goods to obtain a higher margin for his customized goods.

The paper titled "Cost of Customization" discusses a study that was conducted to understand the cost differences of customized and standardized capital goods which are manufactured and assembled by a middle sized company (Sievanen, Suomala, & Paranko, n.d.). Activity Based Costing (ABC) approach has been used to model the cost of manufacturing, sales, purchasing, documentation and engineering activities. The contribution of the study was to point out the need and the use of different activities and the cost associated with them. The subject of this case study which was conducted in 2000 was three products (S, M and L) with standard and customized models. All the customizations had an effect on the assembly process and most customizations were in the "customized standardization"[1] category. Table 2.10 shows the production data that was considered for the case study.

Table 2.10: Production volumes (Sievanen et al., n.d.)

Product	**Standard**	**Customized**	**Share of customized products**	**Total**
S	357	15	4%	372
M	207	56	21%	263
L	61	10	14%	71

Table 2.11 describes the difference in cost of activities. The percentage indicates how much the activity costs of customized products are more in comparison to activity costs of respective standard products. Total costs of customized products were 14% to 19% more compared to standard products.

[1] See Chapter 2: Extent and Points of Customization

Table 2.11: Cost of customized products compared with standard products (Sievanen et al., n.d.)

Costs / Product	S	M	L	Average
Total costs %	119	117	114	117
Materials %	100	104	107	104
Total activity costs %	187	177	138	167
Manufacturing activities %	138	123	116	126
Engineering activities %	379	503	306	396
Sales activities %	287	281	187	252
Documentation activities %	297	293	255	282
Purchasing activities %	127	125	112	121

As there is limited available literature considering the cost of apparel mass customization, it is wise to consider the costs of customized apparel compared to standard apparel, learning from cost analysis such as for the capital goods as shown in the Table 2.11. The highest cost difference is in engineering and as the paper discusses it was due to the significant amount of additional work required for the changes in the design and the increase in the need of engineering during the production to comply with the custom specifications. This is believed to be true for customized apparel that need design changes from the original style. The manufacturing costs are on average about 26% higher compared to standard products. As explained, this was mainly due to the increase in assembly work and partly due to the low production volumes and different and typically more complicated manufacturing specifications. Also the customized products needed special quality control. Mass-customized apparel that need feature customization at assembly may have similar additional activities that incur extra costs compared to particular standard apparel product. As per the information from the cost and profit comparison report by KSA (1997), the manufacturing cost of a basic MC apparel product is about 34% higher compared to the standard product. For a seasonal apparel product the manufacturing cost is about 24% higher and for fashion apparel it is about 19% higher compared to respective seasonal or fashion products. As Table 2.11 describes, a significant increase in sales activity cost was due to the longer sales negotiations, need of more expertise in knowing customer needs, often need of technical support and need of extra information to make an offer. Mass-customized apparel also may incur additional sales and marketing cost as there is a need for one-to-one marketing for individualization. Increase in purchasing cost was due to the increase in complicated invoices and invoice checking and the increase in documentation cost was due to making special manuals for customized products. For mass-customized apparel the purchasing cost can be increased compared to the respective standard products. There were no large differences in the material costs. The customized products have consumed between 38% and 87% more activities than the standard products. It is interesting to evaluate the actual cost of customizing apparel product as it was done for capital goods as discussed in the paper, "cost of customization".

Overall, MC increases the manufacturing cost but eliminates markdowns, stock-outs, and finished goods inventory carrying costs, etc. providing a cost benefit and economic advantage as illustrated by KSA (1997).

2.3.4 Apparel Mass-Customization Practice

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. The following paragraph discusses various research projects and their results that have been carried out in relation to apparel MC.

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).

Piller (n.d.) developed a model with an integrated information flow (Figure 2.16), which can be used to direct managers, implementing or supervising a MC concept.

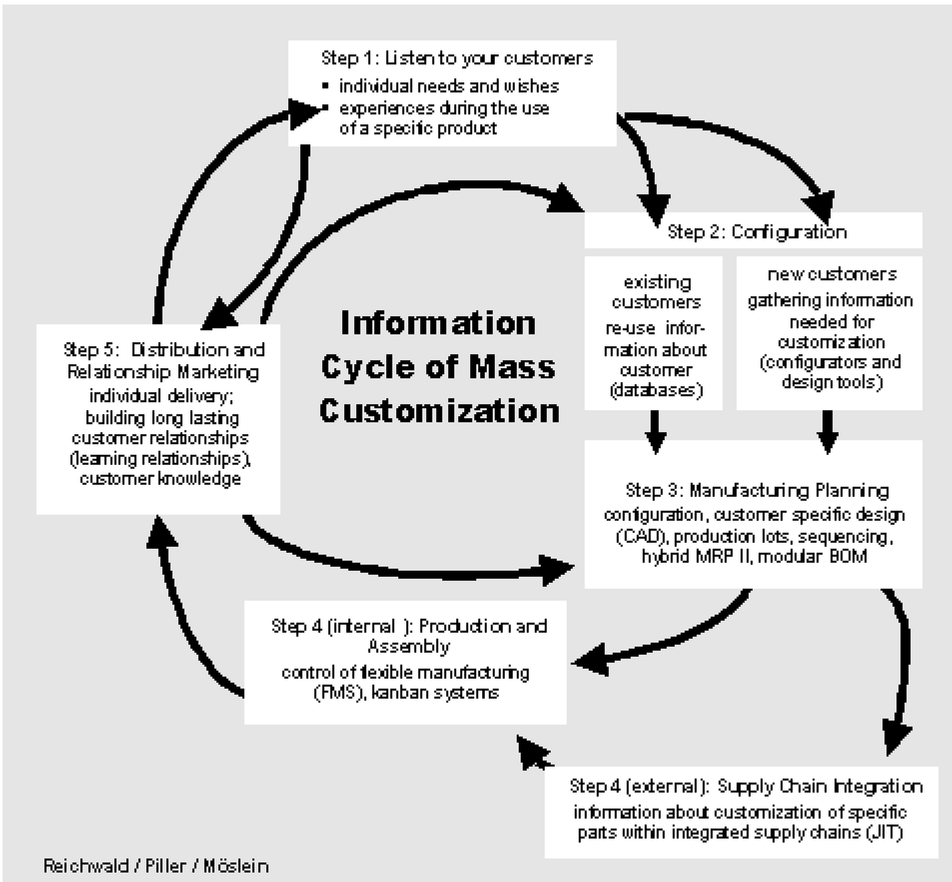


Figure 2.16: The information cycle of MC (Piller, n.d.)

The cycle starts with the individual needs of each customer. The center of each mass customization program has to be 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.

A MC functional model for digitally printed garments is discussed by Chenemilla (2001) as shown in the Figure 2.17. 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.

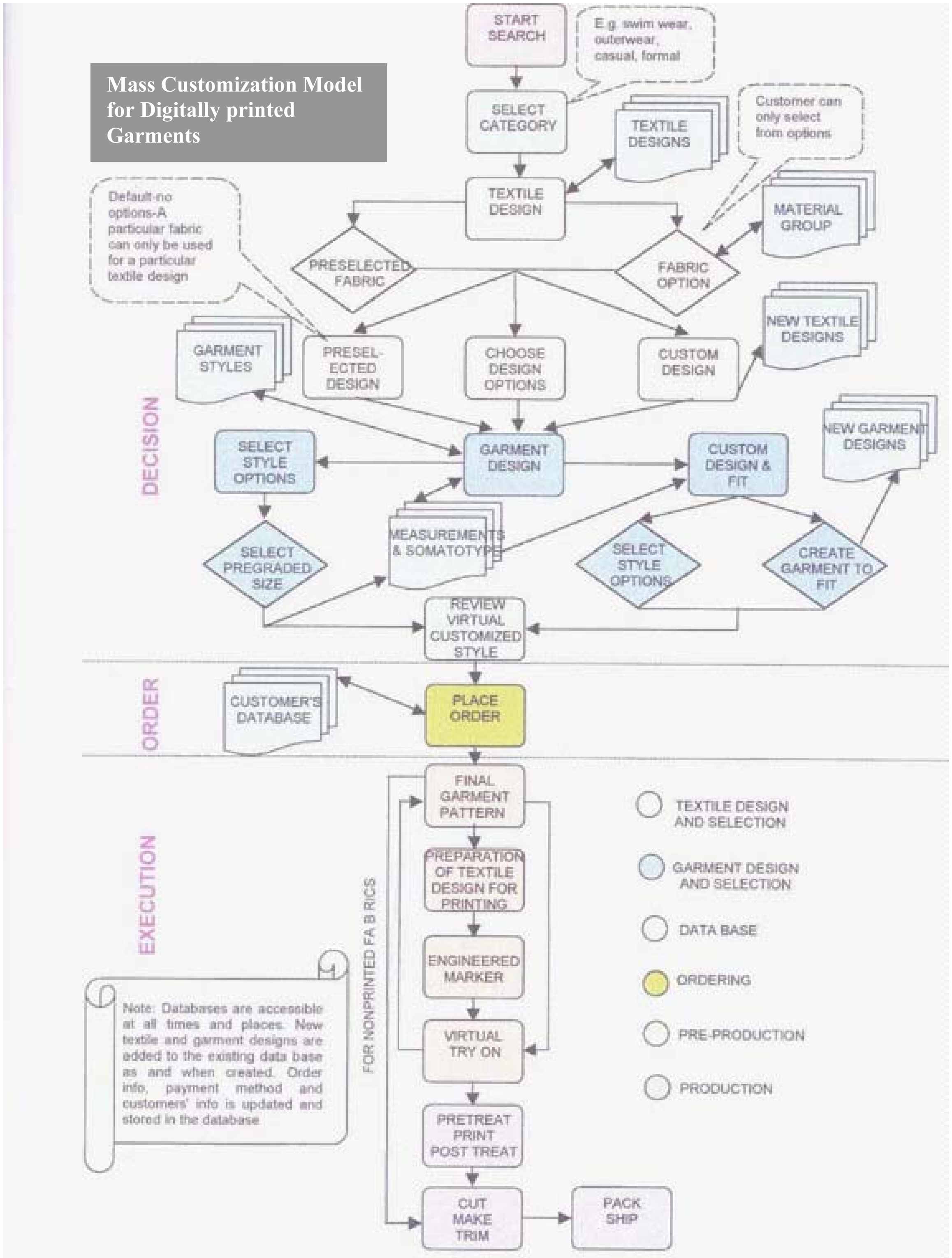


Figure 2.17: MC model for digitally printed garments (Chenemilla, 2001)

These research studies of conceptual and functional models provide valuable information in researching the mixed MC and MP apparel manufacturing. However, none of the models address clearly the customized manufacturing using MP process which is the aim of this research.

2.3.5 Extent of Mass-Customization and Points of Customization

In the MP strategy, the retailers choose to proliferate the market with variety, in effect pushing the variety into the market and anticipating the demands of the customer. While the customer can choose from a mass of products, there is less integration into the manufacturing and design processes. The customer's only input is to purchase or not to purchase. In contrast, with MC, the customer may be involved with the conception of the product, with its design, and working with the designers to best meet the needs of the consumer. This important aspect of customers' ability to enter into the product life cycle and the point at which the influence can be made is described by the Lampel and Mintzberg's (1996) "continuum of strategies" model as shown in the Figure 2.18. The process is described as a series of four processes; design, fabrication, assembly and distribution. Standardization of all processes defines the traditional MP strategy while the other options are developed as the needs of the customer which are progressively integrated with each upstream process. The strategy of pure customization achieves with the customer integrated into the design process. The author will use these strategy definitions in defining the extent and critical points of customization for apparel. As the Figure 2.18 explains, while some industries favor customization and some foster standardization, others such as apparel aim at mixing the two in their products, processes and customer transactions in intriguing ways. In this perspective the extent of customization is an important factor in the mixed MP and mass-customized manufacturing.

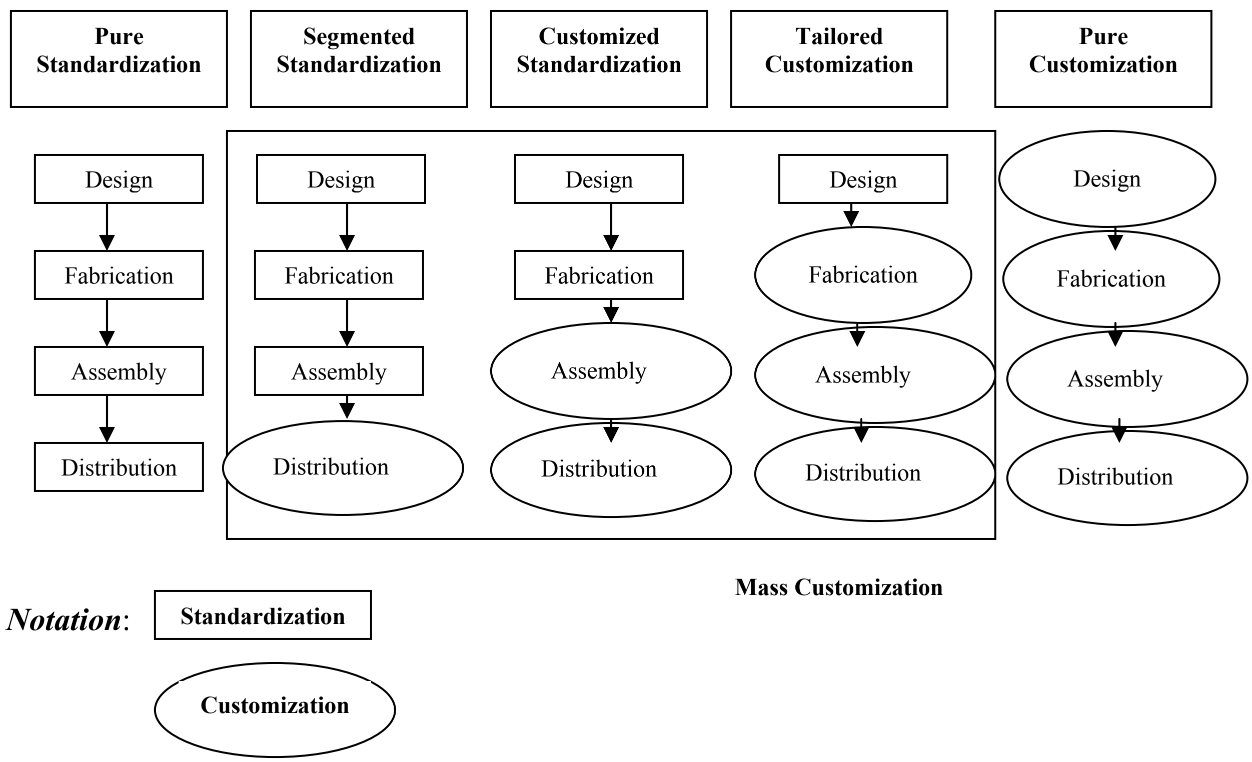


Figure 2.18: Continuum of strategies (Lampel & Mintzberg, 1996)

The Figure 2.19 further explains the levels/layers of customization across the range from MP to MC which is helpful to further understand and identify the extent and the customization based on the various levels from design stage of the manufacturing process. The levels/layers of MC extent is discussed emphasizing the design, production, fit, location, fabrication, and styles whereas the levels/layers of MC intensity is discussed starting from MP and moving towards MC. The results and research analysis section of this paper will use this model with the research strategy to analyze the MC continuum and its linearity considering the MC practice of apparel manufacturing.

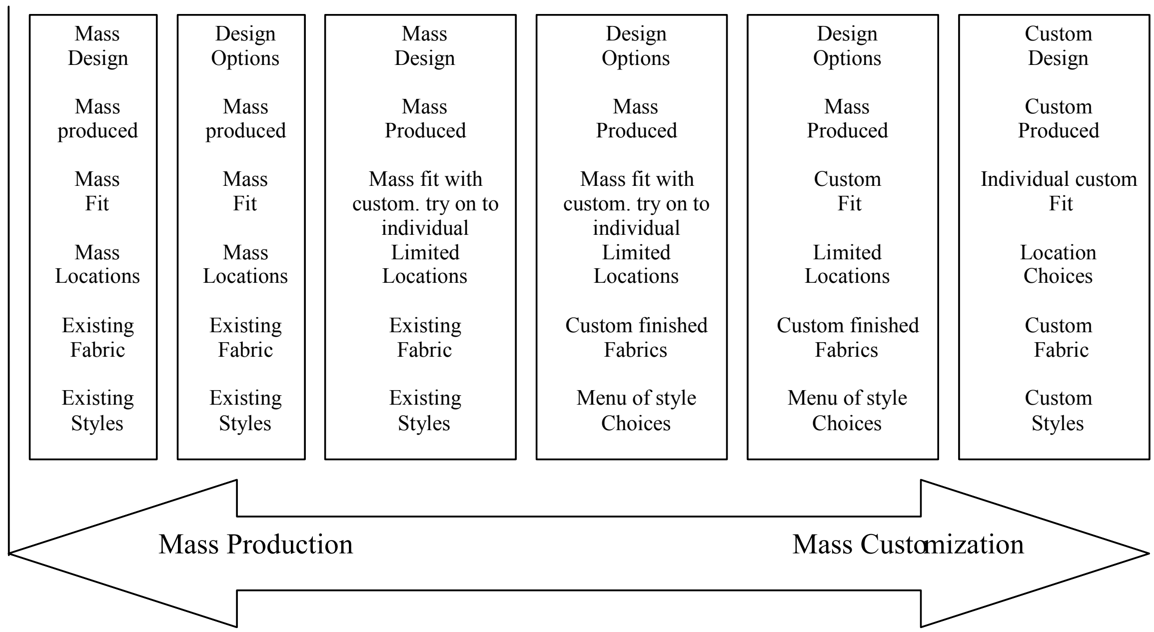


Figure 2.19: Levels/Layers of customization (Anderson, Brannon, Ulrich, Marshall, & Staples, 1995)

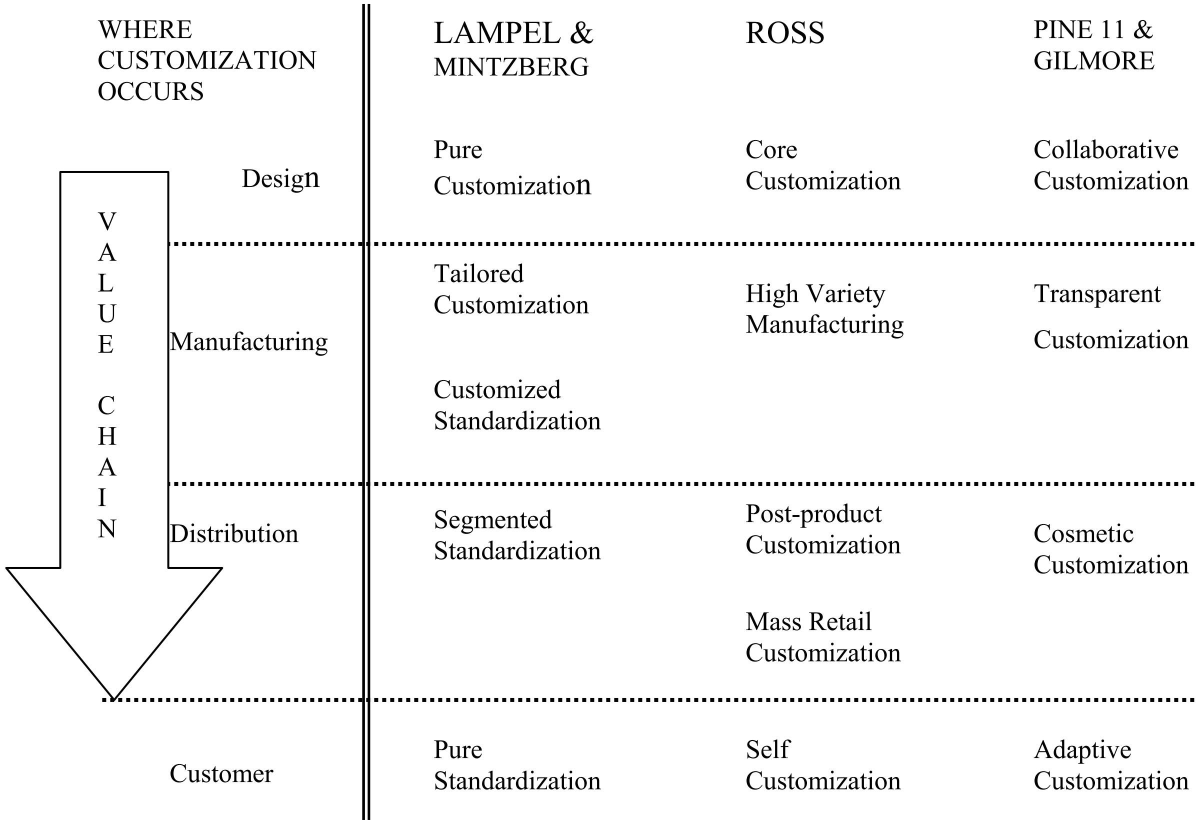


Figure 2.20: Comparing approaches to MC (Alford, Sackett, & Nelder, 2000)

Figure 2.20 shows the various definitions given by authors in approaches of customization showing where customization occurs along the value chain which is divided into four categories, design, manufacturing, distribution and customer. Lampel and Mintzberg define a continuum of five MC strategies (and therefore levels) involving different configurations of process (from standard to customized), product (from commodities to unique) and customer transaction (from generic to personalized)[1] (Silveira et al., 2001). The Pure Customization strategy furnishes products designed and

[1] See Figure 2.18

produced for an individual customer with the customer's involvement in entire cycle, from design through fabrication and assembly through delivery. The Tailored Customization strategy requires a basic design that is altered for a particular customer's preference. Here, the customer enters the production cycle at the point of fabrication where standard products are modified. In a Customized Standardization strategy, a final product is assembled from a predetermined set of standard components where the customer penetrates the assembly and delivery process through the selection of the desired features from a list of standard options (Duray et al., 2000). This customization also can be named Modularization or Configuration where basic design is not customized and components are all mass produced for the aggregate market. Each customer thus sets his or her own configuration but constrained by the range of available components. In Segmented Standardization a basic design is modified and multiplied to cover various product dimensions. But it is not at the request of the customer as in other higher end customization. Individual choice is thus anticipated but not created directly to a request as there is no direct influence from the customer over design and production process and is questionable whether it must be considered as MC with regard to apparel. Under Pure Standardization strategy, the goods are produced as large scale as possible and distribute commonly to the market and there is no distinction between different customers (Lampel & Mintzberg, 1996). But for apparel, MC can be achieved by customizing pure standardized products which is discussed as "post production customization" in this dissertation. These levels of customization are the types of customization chosen by the producer that implies different levels of customer involvement in different points at which that involvement begins. Ross (1996) discusses five approaches for MC providing customers with choice in a mass market. With the exception of Core Customization, Ross's approach focuses on the opportunities available to the manufacturer so that no interaction is required with the manufacturing or design process. A third party between customer and manufacturer can provide the service so that standard products can be altered according to customer needs. Alternatively, a manufacturer may design products enabling customers to change at any time to suit their preferences. Manufacturers also can push variety into the market with the expectations that customers may find what they want. This will not be considered as MC for apparel in the dissertation. In Core Customization most options are already available but collaborate with the customer to change any core elements of design (Ross, 1996). Pine II & Gilmore (1997) describe the customization based on the change in the presentation of the product (Pine-ll & Gilmore, 1997). A manufacturer can customize the product with the collaboration of the customer, called the collaborative customization which is also a similar strategy as the pure or core customization. Adoptive customization enables the customer to customize the product. The cosmetic customizing allows presenting the standard product to each customer differently as expects by the customer. The transparent customizing enables customers to obtain unique products in a standard form (Alford et al., 2000).

Another analysis for existing frameworks for MC to categorize the various levels of customization, proposes a set of eight generic levels, again ranging from pure customization to pure standardization as shown in the Table 2.12 (Silveira et al., 2001).

Table 2.12: Generic levels of mass-customization (Adapted from Silveira et al, 2001)

Generic Levels	Approaches by Gilmore/Pine	Strategies by Lampel et al.	Stages by Pine	Types by Spira
1. Standardization		Pure Standardization		
2. Usage	Adaptive		Embedded customization	
3. Package and Distribution	Cosmetic	Segmented standardization		Customized packaging
4. Additional services			Customized service; quick response	Providing additional services
5.Additional custom work			Point of delivery customize	Performing additional custom work
6. Assembly		Customized standardization	Modular production	Unique config. out of standard components
7. Fabrication		Tailored customization		
8. Design	Collaborative, transparent	Pure customization		

The Design at level 8 refers to collaborative product development, manufacturing and delivery of products according to customers' preference. Fabrication at level 7 represent the manufacturing of customized products based on predefined designs. The next level (level 6), Assembly refers to arranging of modular components in to different configurations as per customer orders. The levels 4 and 5 emphasize achieving MC by adding custom work or service to standard products. For level 3 MC is achieved by providing alternative options to customers for Packaging and Distribution. MC is achieved only after delivery in level 2 with products that can be adapted to different functions or situations. Level 1 refers to pure standardization. When compared with Alford et al. (2000)'s summary of comparing approaches, stages by Pine and types by Spira have not been discussed. Pine has suggested five stages of modular production;

- modular production – standard components can be configured in a wide variety of products and services
- point of delivery customization – additional custom work can be done at the point of sale
- customized services – standard products are tailored by people in marketing and delivery before they reach customers.
- providing quick response –short time delivery of products
- embedded customization – standard products can be altered by customers during use

Types by Spira (Table 2.12) developed a similar framework with four types of customization; customized packaging, customized services, additional custom work, and modular assembly. The combination of these frameworks lead to the above shown eight generic levels of MC (Silveira et al., 2001).

According to Alford, Sackett and Nelder (2000), there are three strategies for customization namely, Form, Optional and Core as graphically shown in the Figure 2.21. In Core customization, most of the options are already available to the customer but collaborate with the customer to change any core elements of design. Optional customization provides the customer to integrate into manufacturing and select from many options so that the product is assembled according to the customer wants. Form customization allows the consumer to customize at the tail end may-be at the distribution center.

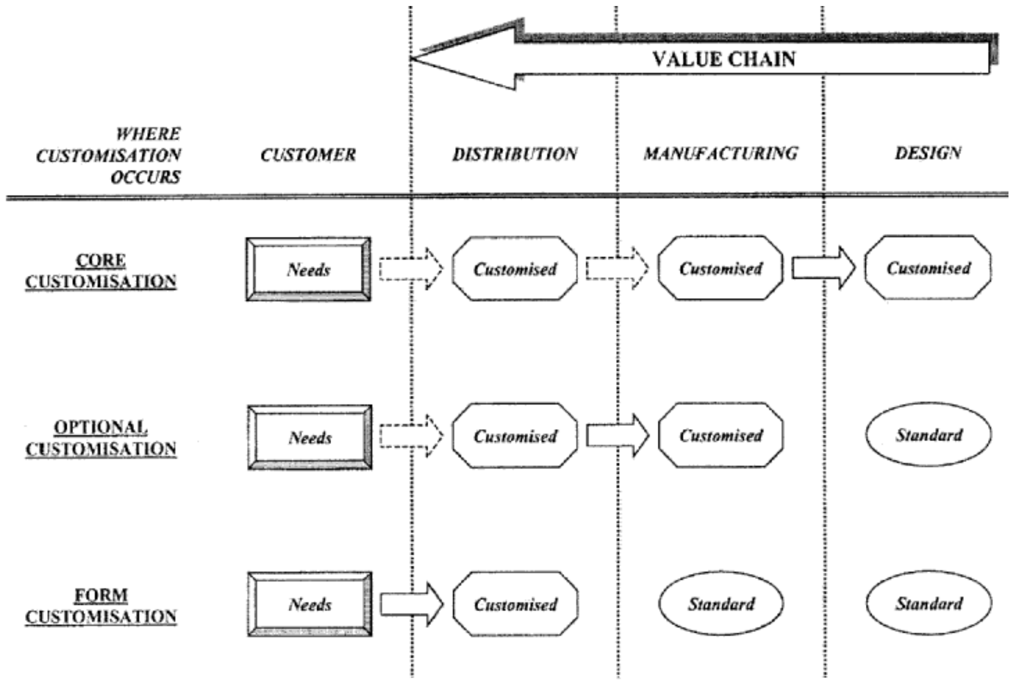


Figure 2.21: Automotive customization (Alford, Sackett, & Nelder, 2000)

Various MC strategies introduced by many experts were discussed. As these strategies were discussed in a general platform, it is required to specifically address them in relation to apparel. As the meaning and application of MC seems different for different people, it is important to understand the concept clearly identifying where it originates in the path of moving from MP to custom manufacturing. The question which is raised is whether the originating point of MC is clear in the MP-MC-Custom manufacturing continuum. Understanding this is important in defining the MC with respect to mixed MP and mass-customized apparel manufacturing.

2.3.6 Contrasting Mass-Customization and Mass Production

Understanding the differences between MC and MP is helpful in researching the mixed MP and mass-customized apparel manufacturing. Pine (1993) argues that:

> In Mass Production, low costs are achieved primarily through economies of scale - lower unit costs of a single product or service through greater out put and faster throughput of production process. In Mass Customization, low costs are achieved primarily through economies of scope - the application of a single process to produce a greater variety of products or services more cheaply and quickly (48) (Pine-II, 1993).

The idea of companies who practice MC is to achieve both economies of scale on standard components that can be combined in a myriad of ways to create end product variety and economies of scope (Pine II, 1999). Pine II (1999), contrasted the "Old Ways" with the "New" as shown in the Table 2.13.

Table 2.13: Contrasting MP and MC (Pine-II, 1999)

The Old Ways of MP	The New Ways of MC
• Low cost, consistent quality standardized product	• Affordable, high quality, customized product
• Homogeneous markets	• Heterogeneous markets and segments of one
• Stable demand	• Demand fragmentation
• Long product life cycles	• Short product life cycles
• Long product development cycles	• Short product development cycles
• Operation efficiency premier	• Total process efficiency premier
• Economies of scale	• Economies of scale and economies of scope
• Long runs	• Lot sizes of one
• Inflexible production	• Flexible production
• High overhead	• Low overhead
• High inventories: build to plan	• No inventories; make to order
• High cost of variety	• Low cost of variety
• Separation of thinking and doing	• Integration of thinking and doing
• Lack of investment in worker skills	• High utilization of and investment in worker skills
• Poor management-employee relations	• Sense of community
• Breakthrough innovations	• Breakthrough and incremental innovations
• Separation of innovation and production	• Integration of innovation and production
• Poor supplier relations	• Supplier interdependence
• Disregard for many customer needs and wants	• Quick response to changing customer desires
• Short term managerial decisions	• Sound long- and short-term decisions by managers and workers

Kotha (1995) compared MP and MC using the literature from Pine (1993) and Pine et al. (1993) by categorizing the features as shown in Table 2.14 (Kotha, 1995; Pine-II, 1993; Pine-II, Victor, & Boynton, 1993).

Table 2.14: Mass production vs. mass-customization (Kotha, 1995)

	Mass production	**Mass customization**
Focus	Efficiency through stability and control	Variety and customization through flexibility and quick responsiveness
Goal	Developing, producing, marketing and delivering goods and services at prices low enough that nearly everyone can afford them	Developing, producing, marketing and delivering affordable goods and services with enough variety and customization that nearly everyone finds exactly what they want.
Key features	• Stable demand • Large homogeneous markets • Low cost, consistent quality, standardized goods and services • Long product development cycles • Long product life cycles	• Fragmented demand • Heterogeneous niches • Low cost, high quality customized goods and services • Short product development cycles • Short product life cycles
Product	Standardized products built to inventory	Standardized modules assembled based on customer needs
Structure	Mechanistic, bureaucratic and hierarchical	Organic, flexible, and relatively less hierarchical

When compared with MP, it is important to understand that the goal in apparel MC is to have sufficient product variety for the customer to select and then customized as per the preferences offered as choices to select from. Berman (2002) contrasted MC with MP under four titles; overall planning and forecasting, source of cost reduction, variety planning, and channel strategy implications. Considering apparel, few modifications were made to Berman's comparison as shown in Table 2.15.

Table 2.15: Contrasting MC and MP (Adapted from Berman, 2002)

	Mass Customization	Mass Production
Overall Planning and Forecasting		
Basis for manufacturing and inventory planning	Actual orders	Forecasts/Orders
Determination of what is sold	Determined by continues demand dialogue between the final consumer and other channel members	Determined by manufacturer/retailer on the basis of demand estimates and the desire to reduce choice so that unit costs can be lowered.
characteristics of demand	Fragmented demand	uncertain demand evn for basic apparel
Unit of analysis	individual consumer	Market segment or average consumer
Objective	Share of customer	Share of market
Size of production unit	Individual unit	lot (Bundle). Can be a single unit out of the bulk
Length of production life cycle	Short	Long
Sources of cost reduction	Just in time delivery, low set up and product changeover costs, production based on the receipt of an order instead of a forecast	Standardized product, considerably long production runs
	Cost economies generated by mass producing modular components that are shared in multiple components. Reduce inventory cost. Information not certain, Research in progress	Cost economies are typically generated through economies of scale. Bargaining power in raw materials in large quantities & reduce production cost
Variety Planning		
Option choice	Consumers able to choose among a very large number of options or self designed	Consumers able to choose one of several alternatives
Variety and production	Creating variety requires flexibility in manufacturing and research in progress	Limited variety is required due to fixed set-ups
Channel strategy implications		
inventory management	Expect little or no finish goods inventory since sales occur before units are produced. May need high raw material inventory. Research in progress.	Need substantial inventory since it is impossible to forecast consumer needs with 100% accuracy
	Can offer thousands of different options and sizes without having to stock the exact configuration that was ordered	Substantial inventory required at all channel levels due to uncertainty in forecasting both total demand and demand for specific units.
Cash flow	Cash flow facilitated because goods are sold and at least partially paid for before they are produced	Cash flow impeded by large inventories at manufacture, whole saler and retailer
Pricing basis	Pricing determination model does not have to include mark downs, high inventory accumulation, and customer returns	Pricing determination model must include mark downs, high inventory accumulation and customer returns
Role of the retailer in the channel	As a problem solver that can articulate customer needs and then translate them into a unique product/service	In addition to problem solving retailers perform credit and inventory functions by purchasing and stocking large inventories before they are sold to final consumers
Production focus	Focus on need to reduce set-up and changeover times, short product development cycle, lean production enables low costs even at small volumes One of the objectives of this research.	Focus on economies of scale and repetition to cut per-unit costs, long product development cycle, reduced costs through high volumes and economies of scale
Promotion focus	Narrowcast	Broadcast or aim at specific segment
Logistics focus	Ability to sort individual quantities based on customer orders	Ability to sort large quantities of orders for identical merchandise
Supply chain	Highly coordinated. Producing, sorting, shipping and delivering of small quantities of highly differentiated products	Large quantities of identical products

The MP companies that expect to move into MC business need to learn how the transition must take place and what requirements they need in the total business model. Figure 2.22 illustrates a set of steps that a mass-producer needs to undergo to become a mass-customizing company as proposed by Tseng & Piller (2003). The focus is to organize functions related to the service, customer focus, process, time and product with conservation of cost advantages (Tseng & Piller, 2003). Individualizing the service to "one" comparing to "many", providing the ability for the customer to customize the product to a considerable extent, organizing the flexibility of the manufacturing system to be able to become a "customer specific", speeding the order processing system so that the order can be delivered within the expected time frame, and designing the products with principles and techniques for MC apparel manufacturing are key elements that are discussed as important features for a mass producer to become a mass customizer.

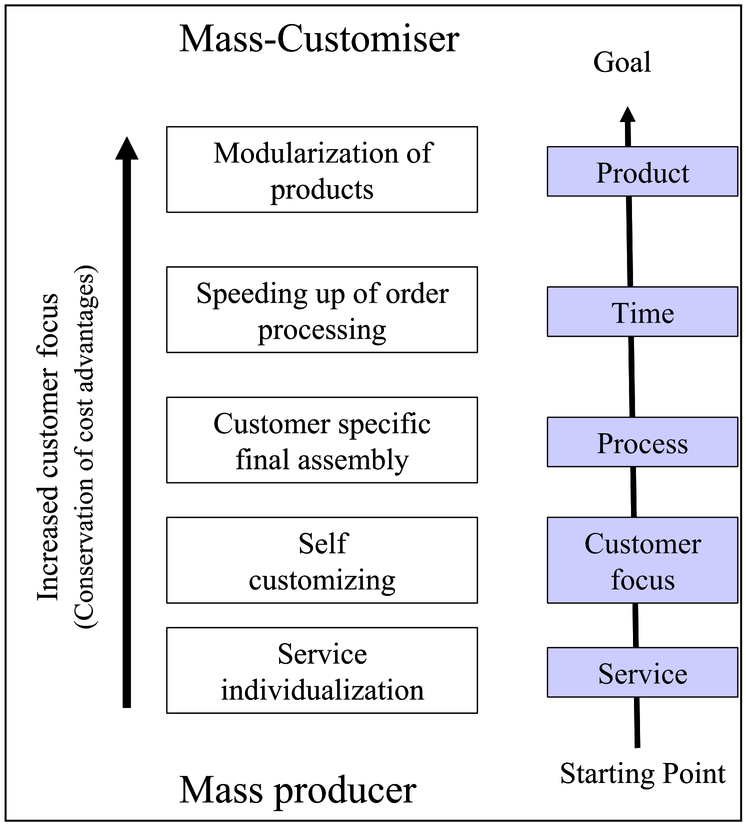


Figure 2.22: Starting points: MP to MC (Adapted from Tseng & Piller, 2003)

2.3.7 Principles and Techniques for Mass-customized Manufacturing

Several ways to mass customize products are discussed in the literature out of which modular, dimensional and adjustable customization are discussed in detail. Postponement, Standardization, Delayed Product Differentiation, and Customization from Forecasted Parts Inventory are other principles that are used in achieving mass-customized manufacturing. It is important to study these existing principles and techniques in consideration whether they can be used and how they can be used in mixed MP and MC apparel manufacturing.

2.3.7.1 Modular Customization

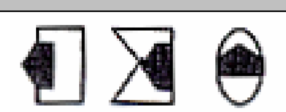
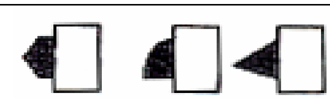
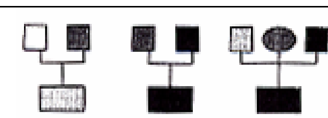
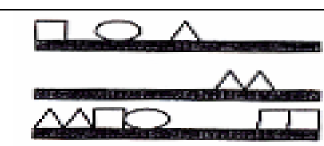
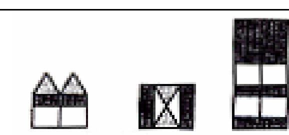
Modular customization refers to assembling modules of varying combinations to customize products (Anderson & Pine-II, 1997). It can be seen that most of the attention on MC has gone to modularity for many products as it is relatively easy to practice with the existing MP practices. This is also can be practiced with 'out-sourcing' strategy as popular with automobile and computer industry. If modules have significant variety, the problems pertaining to high verity such as forecasting difficulties, out-of-stock, over production, excess inventory, obsolescence and delays will cause the MC practice inefficient (Anderson, 2003).

Virtual Modularity is a sub-set of Modularity which does not limit products to physical modules. Drawings of virtual modules can be combined and assembled using CAD systems, which can be customized, as customer needs. Hidden Modularity is another division of Modularity which provides customers to develop an integrated product. Product that can be assembled from various choices of modules to be assembled into what appears and perceives by the customer as an integrated customized product has a hidden modularity (D.M. Anderson, 2003). As the author suggests, Virtual and Hidden Modularity are possible techniques that can be practiced in the apparel MC.

Pine (1993) argues that modularity is a key to achieve MC. This provides a means for repetitive production where customization can be achieved via combination or modification of the modules. Modularity allows part of the product to be made in volumes as standard modules so that custom parts can be manufactured with MP techniques. Modular product design supports a way to provide variety and speed, thereby enhancing the customization responsiveness. This approach reduces the variety of components while offering a greater range of end products. This also shortens the delivery leadtimes to provide economies of scope. Modularity in the product design, facilitates flexible manufacturing systems for low cost customization through fast set-ups (Duray et al., 2000).

In addition, Component Sharing, Component Swapping, Cut-to-Fit', Mix, Bus, and Sectional are types of modularity that are discussed in the literature, which can be used separately or in combination to provide a customized end product (Ulrich & Tung, 1991). These are discussed in Table 2.16 with some examples.

Table 2.16: Types of modularity (Ulrich & Tung, 1991)

Type of modularity	**Verbal Description**	**Visual Description**
Component sharing modularity	Products are uniquely designed around a base unit of common components.	
Component swapping modularity	Modules are selected from a list of options to be added to a base product.	
Cut-to-fit modularity	Alters the dimensions of a module before combining it with other modules.	
Mix modularity	Similar to components swapping, but is distinguished by the fact that when combined, modules loose their unique identity.	
Bus modularity	Ability to add a module to an existing series, when one or more modules are added to an existing base.	
Sectional modularity	Similar to components swapping, but focuses on arranging standard modules in a unique pattern.	

The Cut-to-Fit modularity can be named as one that is used in the apparel to customize fit. Cut-to-Fit and Component Sharing modularity demand that components are newly designed or changed and therefore must take place during the design and fabrication stage of the manufacturing process. Modularity incorporates with the standard base in Component Sharing simplifies fabrication and reduces the cost of customization. Component Swapping, Sectional, Mix and Bus modularity provide customization by allowing customers to specify a choice among standard modules without the option of altering any of the modules. Sectional modularity can be a combination of products from several manufacturers combined for customization (Ulrich & Tung, 1991). Modularity restricts the range of choice to the customer but allow repetitiveness for the manufacturer. When modularity is employed in MC, product distinctiveness is a result of either the combination of standard modules in to a finite number of permutations or the alteration of prescribed modules in to a limited range of products. Modularity bounds the degree of customization to a considerable extent in apparel.

It is important to consider the customer involvement in the production process with the modularity type that is used. In the design and fabrication stage the modules can be altered for customer preference but at assembly and use stages the modules are added or interchanged but not altered. The first two stages represent a time in the production cycle when customer preferences require a physical alteration of existing components or manufacturing unique components. Based on the point of customer involvement and type of modularity, four groups of mass customization types are discussed as illustrated in Figure 2.23.

	Type of Modularity			
Point of customer involvement	Design	Fabrication	Assembly	Use
Design	Fabricators		Involvers	
Fabrication				
Assembly	Modularizers		Assemblers	
Use				

Figure 2.23: MC configurations (Ulrich & Tung, 1991)

Fabricators involve the customers in the beginning at design and fabrication stage to come up with unique designs or major revisions to existing products. Research addresses this customization extent in reference to Design, Fit or Fabrication customization[1]. Involvers incorporate customer preferences in the design and fabrication stage but use modularity in the assembly and delivery stages. Feature Customization is an example which addresses this thought in the dissertation. Modularizers use modularity in early stages of the production cycle but will not get customer involvement until late stages. The assemblers provide MC by using modular components to present a wide range of choices to the customer. They more closely resemble the operations of MP than the other

[1] See Chapter 4: Points of customization

configurations of mass customizers. Post Production Customization[1] resembles both Modularizers and Assemblers.

To what extent modularity can be used in the apparel manufacturing needs to be explored. For example, modules can be parts that are cut and made to be used for various styles, even though this has not been found in literature as a popular practice for MC of apparel.

2.3.7.2 Adjustable Customization

As the name implies Adjustable Customization provide the ability of the product to be customized by adjusting the features. Adjustments can be manual or automatic. An automatic adjustment can be a washing machine that can select a cycle automatically from available 600 washing cycles and a manual adjustment can be a seat position in a car or an office chair (Anderson, 2004). An advantage in this customization is that it still can be mass-produced without having to forecast choices, build in many versions of variety of products. The practice of alteration that was in existence from a long time for apparel can be considered as the Adjustable Customization. The companies have also tried to use this principle to customize apparel in many instances such as in athletic apparel, footwear, swim wear, winter clothes, etc. For example, user control manual adjustment can be a waistband adjustment of a pant using the band-button attachment.

2.3.7.3 Dimensional Customization

Dimensional customization refers to permanent dimensional change such as cutting-to-fit or tailoring. This way of customizing can be performed automatically by computer numerical control (CNC) equipment such as single ply cutter for apparel (D.M. Anderson, 2004). As discussed in the modularity section, Cut-to-Fit modularity can be related to Dimensional Customization. In this research, this can be referred to Fit Customization[1]. The machines can be controlled by programs which can be changed instantly providing a high flexibility for the manufacturing process. Automatic pattern adjustment, automatic marker making and automatic fabric cutting help dimensional customization for apparel. It is also important to remember that to improve the efficiency of this process by reducing setup, the raw material has to be standardized or the variety needs to be reduced.

2.3.7.4 Postponement

Postponement is a mass-customization technique that is "suitable for a product architecture that has a major platform part that can be built without variation and then customized by various adjustments, configurations, or bolt-on modules" (Anderson, 2003). This technique is useful for companies who mass produce or outsource their products and still have some capability to achieve customization before shipping to customers. Dimensional and Adjustable customization provides a wide range of

[1] See Chapter 4: Points of Customization

customizing options but modular customization would be good for standard modules. This technique is introduced as the Post Production Customization by the author[1].

2.3.7.5 Standardization

Standardization is another principle that is used in the MC manufacturing. This provides the product flexibility for the manufacturing system. The standardization strategy for apparel need to be addressed in a different way than other products as there is a fashion element involved in the product it self.

Standardization of parts and materials is an important prerequisite for the build-to-order and mass-customization which will simplify product development efforts, lower costs of parts, material and material overheads, simplify supply chain management, improve availability and deliveries of materials, improve serviceability, fast response, easy material management and reduce manufacturing complexity (Anderson, 2003). In the customization point of view, the options that the customer is offered can be standardized. Standardization limits the extent of customization but facilitates the production to be efficient and allows faster throughput time thus faster response. For example, instead of allowing the customer to customize the style and placement of a monogram in unlimited ways, the manufacturer can offer few styles and places of the main style so that customized manufacturing can be simplified.

It is beneficial to look at the customizing apparel style and see what can be standardized without harming the extent of customization expected by the consumer. By looking at the companies who practice MC and requests from consumers, Fabrication

Feature and Fit Customization [1] can be seen standardized to some extent in many cases. For example, standardization can be done in relation to sewing thread (limited thread type for shirts with appropriate colors), fabric and color (limited fabric color and type options), feature types (limited collar and cuff style options) and fit (loose fit or boot cut jeans).

The drawbacks of part proliferation can be eliminated with the strategic design of the products, but still satisfying the diversified consumers. The more the variety of parts, more costly it is. The product development for mass customization needs to address this issue.

In relation to mass-customization of apparel a good approach in standardization is to standardize the customization offerings such as Fabrication, Feature and in some cases Fit. Standardization of parts helps to reduce set up and improve flexibility in the mass-customized manufacturing. Anderson (2004) discusses part standardization and how machinery and tool standardization help mass-customized manufacturing. Standardization of feature offering to customers helps to standardize the processes and machines needed for manufacturing. As discussed, standardization of materials, machines, designs, features and processes improve the manufacturing flexibility and quality, reduce cost and supply chain complexity and improve responsiveness. The reader must understand that the extent of standardization for MC is different from what was discussed in MP.

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[1] See Chapter 4:Points of Customization

2.3.7.6 Delayed Product Differentiation

Delayed product differentiation (DPD) is a design concept and a technique aiming at the increase of product variety and manufacturing efficiency. Increasing the level of part commonality at the early stage of the manufacturing process will help to delay the product differentiation. DPD refers to delaying the time when a product assumes its identity (He & Kusiak, 1995). Commonality here is defined as the use of a component by several different products. It is required to manage the part commonality so that it will not adversely impact the performance of the manufacturing system by way of increasing the inventory, manufacturing and material handling cost. In DPD, common and simple parts are machined and then delivered to the assembly system to form product variants (He, Kusiak, & Tseng, 1998). Other design strategies such as Modular Product Design facilitate for DPD by number of common parts serving numerous product models. The opposite of DPD is the Early Product Differentiation. Designing parts as per the DPD concept is referred to as Differential Design and designing parts for early product differentiation is referred to as Integral Design. Most products are designed by combining these two systems (He et al., 1998). Differential Designs cause the number of assembly operations to be increased thus the increase in assembly time and may need additional assembly stations which will affect the balancing of the system.

No literature was available specifically in relation to apparel DPD but the concept as the author suggests is similar to Post Production Customization[1]. This is because it is

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[1] See Chapter 4:Points of Customization

not easy to have a part commonality with the cut fabric parts generating different styles in the mass-customized apparel manufacturing. However, this concept can be applied to cut parts such as interlinings that are ready to sew which can be adjusted at the assembly operation as needed for style variation. Also, the concept can be applied as having a limited fabric option for customization that can be cut and used for different styles in assembly.

This concept is considered as an assembly driven strategy in literature which is compatible with the terminology in this research as Feature Customization[1]. When the customization is not dimensional or the interest is for common sizes with features customized, this concept can be applied to a considerable extent in the apparel. For example common collars, cuffs, pockets, etc. can be common parts for a shirt style which can be differential designs that may be assembled to order based on component modularity.

2.3.7.7 Customization from Forecasted Parts Inventory

One of the ways to customize products is to draw parts from the forecasted inventory and assemble-to-order modular parts (D.M. Anderson, 2003). In case of apparel this may be once again the Post Production Customization[1] where already produced apparel products are customized as per customer requirements. Athletic apparel is one good example. Also, the basic modules such as fusible interlinings can be cut and

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[1] See Chapter 4:Points of Customization

kept for future usage. The fabrics may be cut to the general length for a single size marker and preserved in anticipation of orders. One of the disadvantages is the carrying cost involved. Knitwear is another example where the yarn can be from the forecast and made-to-order for customization. The reader is informed that most of these examples related to apparel manufacturing are suggested by the author and may not be in real industry practice for apparel MC at the time this dissertation is written.

A compiled table of principles and techniques of customization with examples relating to apparel MC are discussed in the Research Findings and Results Chapter.

2.3.8 Inventory Systems for Mass-customized Apparel Manufacturing

The practice of having inventory at various stages in the MP process has to be considered appropriately for mixed MP and mass-customized apparel manufacturing. Carrere (1997) reviewed literature for existing inventory models for responsive apparel replenishment in detail. Cheng et al. (2002) in their article "inventory service customization in configure-to-order (CTO) systems" discuss that CTO appears to be the ideal operational model that provides both MC and QR time to order fulfillment. One aspect of the model is to study optimal inventory service trade-off effect of MC as a result of direct sales over the internet for computers (Cheng, Ettl, Lin, & Yao, 2002). Research on inventory models for MC is limited in literature and as it may be required to manufacture an order of one, it is important to explore how to model the inventory aspect in MC. To be successful in customized production the supply chain needs to be organized in such a way that Kanban supplies or automatic replenishment will replenish the required material. This automatic part supply will be successful with standardization of parts required for the manufacturing process (Anderson, 2003). As the availability of raw materials is of great importance that enables mass-customized manufacturing, it is important to identify the inventory models for both raw materials as well as finished goods based on the extent of customization. This would be another important research direction in mass-customized apparel manufacturing.

2.3.9 Order Entry and Information for Mass-customized Manufacturing

The order entry system for MC is widely different from the MP system (Anderson, 2003). Customization data or dimensions needs to be specified and the leadtime for order process has to be very short for MC orders. The companies who practice MC may need effective web sites and other ways of information systems that can rapidly handle a wide variety of orders through configurators and convert order entry data into CAD systems, CNC programs, assembly and shipping instructions. The configurators are software programs that can explore what if scenarios instantly for customer requests based on allowed customizing options. They may keep a track of all the options, features and all the rules that apply to their selection. Further, configurators are expert systems that cut short the lengthy scenarios that were practiced previously to communicate customer needs to the plants. It is possible to mention that these systems can capture the knowledge of the company experts. Configurators can be on sales person's lap top computer or company web site that provides the customer to co-design the product in various ways such as to include body scans for clothing and foot scans for footwear. The advanced configurators have the ability to display solid models and advanced graphics to show how the product will actually looks like (Anderson, 2003). An example from apparel industry is the “my virtual model” (My-Virtual-Model, n.d.). Web based configurators offer the customer to place the order after designing the product based on the valid configuration options. Once the configuration is finalized and order is approved the information is sent to the order entry data base which accepts information and converts it into various data packets that is used for various operations. In case of apparel manufacturing, these data packets may be used in pattern selection and alteration, marker making, cutting, assembly, finishing, packing and shipping.

The efficiency in information transfer from customers to manufacturers is imperative for a successful MC business. The manufacturer must define to what extent customer may customize their order based on manufacturing capabilities. Customers provide the information on their choice of design elements. The interface of customer and manufacturer must be uniquely defined according to the company which develops and implements the MC program. The customer-manufacturer communication link involves the following steps (Silveira et al., 2001);

- defining a catalog of options to be offered to customers or the degree of customization offered
- collecting and storing information on customer choices
- transferring data from retailer to manufacturer
- translating customer choices into product design features and manufacturing instructions.

Collecting and storing information on customer choices can take place in many different ways based on the specific MC practice. Customization data can be obtained from sales person's interaction with the customer, filling and selecting website fields, and filling out paper forms. Data on customer choices may be gathered by a store employee or sales representative who is trained to guide the customer through the decision process, or may be collected using a computer interface with minimum human interference. The customer and the designer may also jointly develop a product or a part of the product. Information is commonly stored in order sheets or electronically using a computer system. Genetic algorithms and other autonomous agents can also be presented as facilitators during the information acquisition process. During the transfer of information from store to the manufacturer, it is required to generate a product ID, such as a barcode for order tracking purpose throughout the pre-production, production and post-production process. As author suggests, order tracking is an important element in the mixed MP, MC manufacturing. Information transfer in more recent practice use internet as the means to link the store and the manufacturer.

2.3.10 Product Design and Development for Mass-customized Manufacturing

Design for MC aims at considering economies of scope and scale at the early design stage of the product realization process. The emphasis is on elevating the current practice of designing individual products to designing product families. To support customized product differentiation, a product family platform is required to recognize customer needs and subsequently to fulfill these needs by configuring and modifying well established modules and components. Therefore, it is important to look at the product family architecture and product family design which are basic concepts underpinning the design for MC (Tseng & Piller, 2003). Design for customized manufacturing requires design engineers to take a broader perspective in addition to the product functionality and performance (He et al., 1998).

The book "Agile product development for mass customization", discusses various strategies to develop products for MC, niche markets, build-to-order and flexible manufacturing environments. The product definition for families of products and product line architecture will determine various ways of customizing products such as modules, adjustments and dimensional customization that were discussed before (Anderson & Pine-II, 1997). Anderson (1990) addresses different approaches to design products with the least time and cost, with the quick and smooth transition in to production, with relevant quality and reliability to satisfy the customer needs and compete in the market place (Anderson, 1990).

During the product development process for mass-customized manufacturing, it is important to have a good coordination with the fabric and accessory suppliers so that the exact match of what is offered to customers can be procured. It is also important to identify the machine capabilities in developing products for MC. Designers will try to limit the features that is offered for customers so that to improve the flexibility of machines and processes used for manufacturing. For example, one aspect of flow manufacturing is the dedicated cell or line, which may be arranged to build any variation within product family with minimal setup. The product family in the case of apparel may be one category of an apparel line such as dress shirts, blue jeans etc. The criterion for products to be manufactured in MC is that the product group must be able to manufacture efficiently on demand with a batch size of one (Anderson, 2003). Jiao and Tseng (1999) presents a methodology of developing product family architecture to rationalize product development for MC in terms of functional, technical and physical views. The diverse needs of customers are matched with capabilities of a firm through systematic planning of modularity. A case study is also presented to illustrate the feasibility of the study (Jiao & Tseng, 1999). These methods must be studied in understanding product families and their architecture for customized apparel manufacturing which is important for mixed MP, MC apparel manufacturing.

2.3.11 Strategies from Literature for Mixed MP and MC Apparel Manufacturing

Figure 2.24 shows a cause and effect diagram exploring the impact on the implementation of Optional customization with respect to automobile manufacturing system.

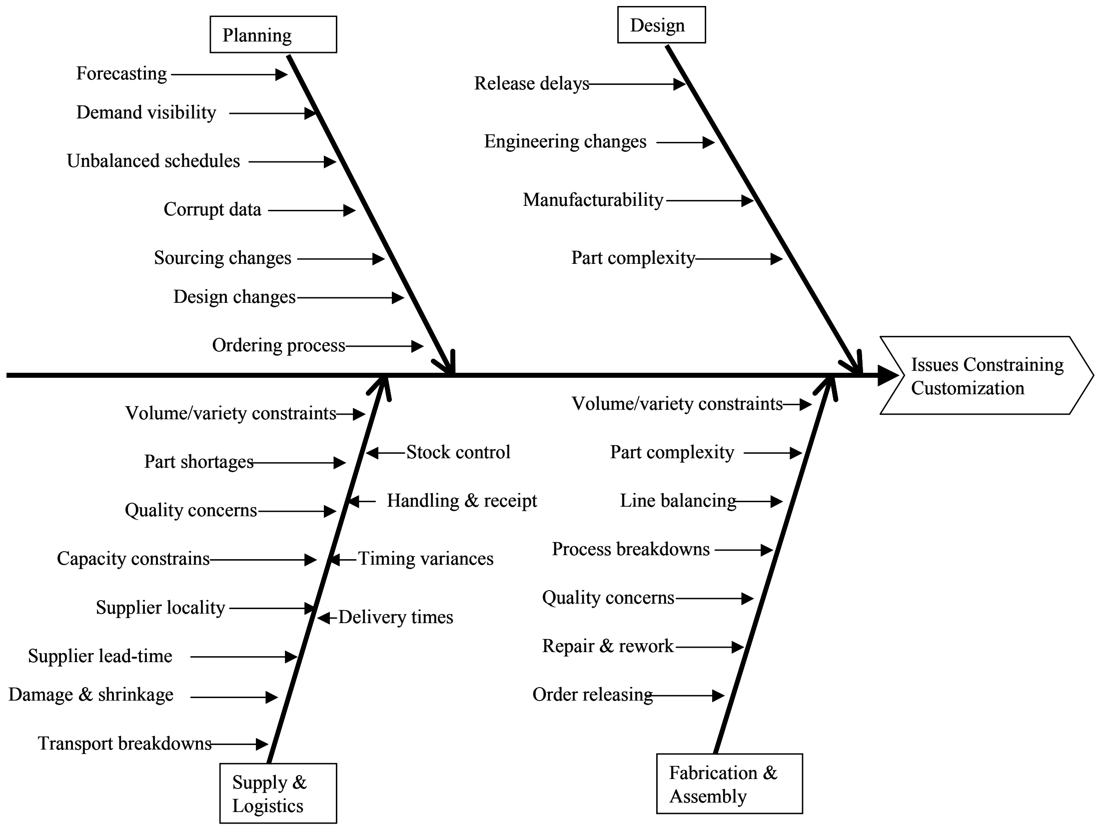

Figure 2.24: Issues constraining customization (Alford et al., 2000)

Under the main parent cause of "issues constraining customization", four other parent causes are shown. Under each of these Parent Causes, Child Causes are revealed. Although it is discussed for automobiles, most of these causes are common even for apparel MC. According to Alford et al. (2000), "existing facility layouts, installed technology and established work practices constrain the realization of manufacturing capabilities for increased customization. Furthermore, these capabilities can not be realized by removing existing issues in isolation". This information can be modified and used for research in mixed MP and mass-customized apparel manufacturing. For example, additional child causes such as MP system leadtime, process differences, batching complexity, extra machines, WIP inventory, operator skills, etc. can be added under the fabrication & assembly parent cause. Considering the cause and effect diagram in Figure 2.24, the capabilities of customization has been developed as shown in the Figure 2.25 (Alford et al., 2000). These causes that need consideration in MC are explored within design, fabrication & assembly, supply & logistics, and planning. These can be matched between the points and extents of customization that were discussed under the topics of design, fabrication, assembly and distribution to better understand the issues that may need to be resolved in mass-customized apparel manufacturing. The capabilities of MC that are discussed as shown in Figure 2.25 can be helpful in resolving these issues.

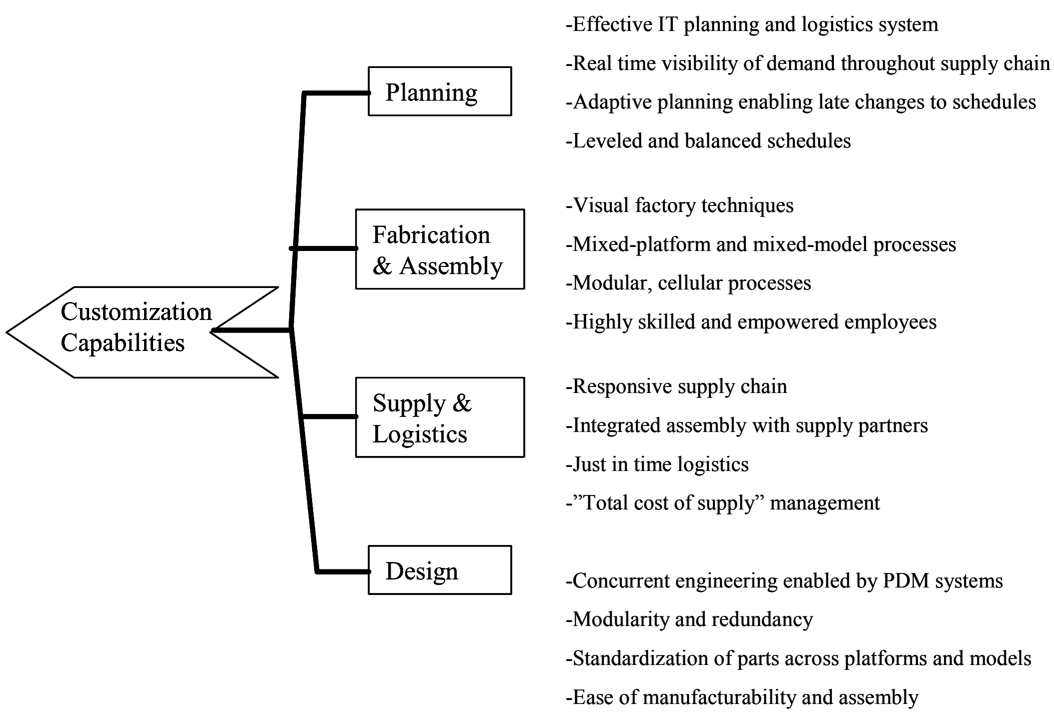

Figure 2.25: Capabilities for MC (Alford, Sackett, & Nelder, 2000)

According to Guoning (n.d.), “the basic idea of mass customization is that the production problem of customized products can be converted into the well-known problem of mass production through reorganization of the product structure and the manufacturing process”. As he discusses, with the arrival of the order, the customized production begins on the base stock or pre-manufactured parts. In the production process it is the Customer Order Decoupling Point (CODP) and at this point the predicted production of MP is changed into the customized production in order to respond to the customer demand (Guoning, n.d.). This principle of CODP is shown in Figure 2.26. As the author highlighted in the previous section, this transition point is very important in researching the mixed MP and mass-customized apparel manufacturing.

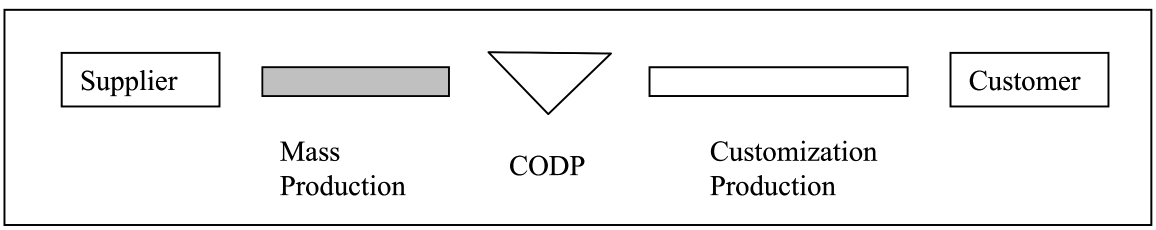

Figure 2.26: The principle of CODP (Guoning, n.d.)

This notion of CODP is discussed as a point up to which a customer is involved in the final specification of the product. The paper written by Thoban in the book, ‘The Customer Centric Enterprise’, discusses that Wortman (1997) refers CODP as a point in the material flow from where customer order driven activities take place (Wortmann, 1997). The customer’s influence on the product can range from the definition of some delivery related product specifications in end processes in the product life cycle such as packaging and transportation to modification of the product in the very early stages such as design (Tseng & Piller, 2003). This concept of CODP is shown in Figure 2.27. Based on the point of customer's influence, four manufacturing strategies are discussed.

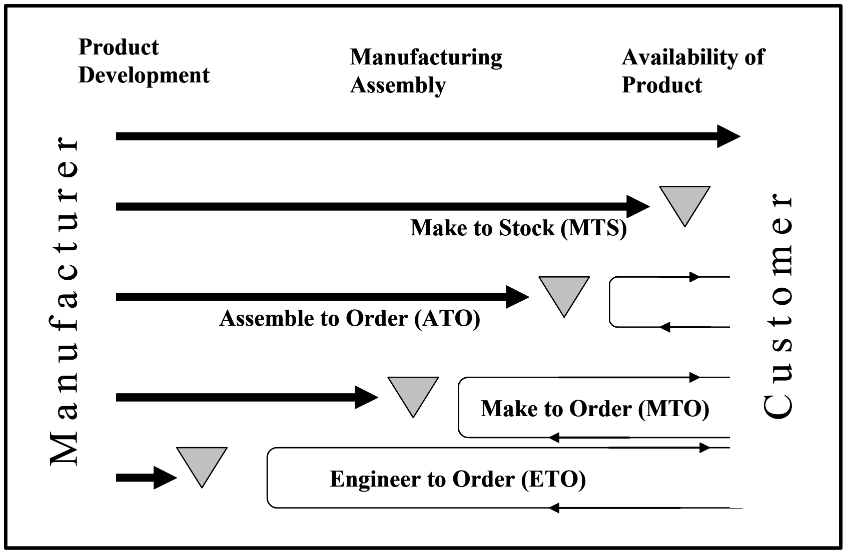

Figure 2.27: Typology of customer order decoupling point (Wortmann, 1997)

Based on the CODP principle, the transition from MP to MC is discussed by Guoning (2002) as shown in Figure 2.28. The same manufacturing strategies are discussed in relation to suppliers and customers. The point at which CODP applies between supplier and customer are represented by material, part, unit and product in comparison to Wortmann's (1997) product development, manufacturing and availability of product. The sale-to-order (STO) [or make-to-stock (MTS)] is considered to be in the MP mode where sales activity is driven by the order of the customer. In the assemble-to-order (ATO) production strategy, company reconfigures the existing parts to supply customized product after the order is received. In this case the assembly and following activities are driven by the order of the customer. In make-to-order (MTO) production mode the firm re-designs, manufactures and assembles parts based on the existing parts and a customized product is supplied to the customer. In the engineer-to-order (ETO) production strategy an enterprise re-designs new parts or a whole product that meets the specific needs specified by the customer. This product may be fully customized. In actual production, the borderlines are not as distinct as discussed and can be overlapped. It can be seen that, as the degree of customization increases the CODP moves in a way that the ratio of MP to MC gets smaller. “The core strategy of mass customization is to improve the proportion of stock production, to move the CODP towards the lower part of the production process as far as possible, to reduce all kinds of cost of design, manufacturing and assembly and at the same time to meet the specific needs of the customer’s order (Guoning, 2002). In relation to apparel, the garments can be made to stock and then customized for a customer’s request which is considered as the Post Production Customization in the research. Assembly-to-order manufacturing has not been discussed. Make-to-order apparel manufacturing with re-designing existing styles is some what popular in apparel MC. The Engineer-to-order system for apparel can be changing patterns for Fit Customization[1].

[1] See Chapter 4:Points of Customization

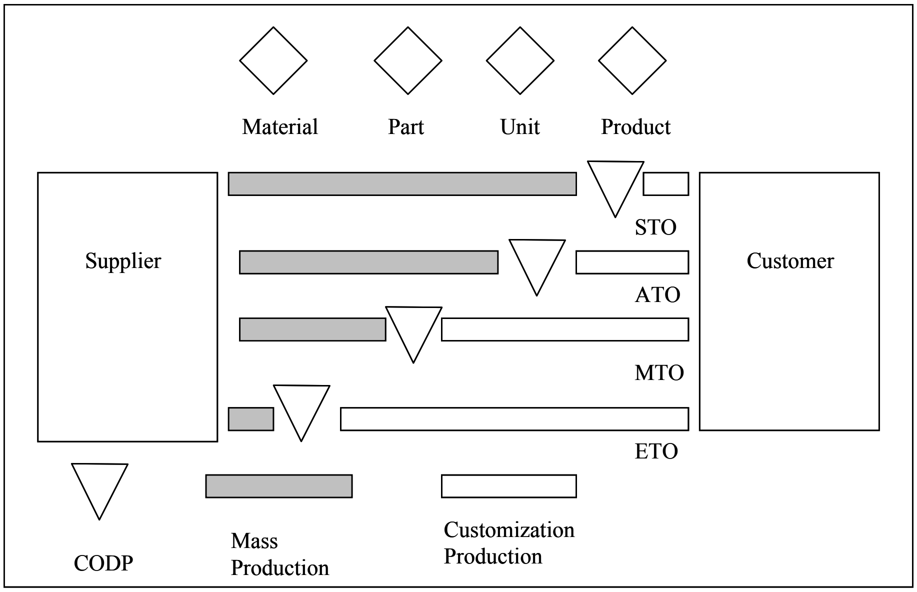

Figure 2.28: The transition from MP to MC (Guoning, n.d.)

2.3.12 Mixed MP and MC Manufacturing

To make the MP process more flexible and responsive, companies have made efforts in various ways. Some of these are very expensive capital investments such as warehouses and distribution centers with automated equipment to handle the process. Also, some companies are trying to sell from inventory using web-based programs and try to imitate build-to-order concept. Companies have spent large amount of money for software systems to make the inflexible MP process flexible or to improve the forecasting process more reliable. Taking in to account the rising labor cost, most of the apparel manufacturing has been out sourced which has made operations less flexible and less adept in handling variety. However, a better approach to cater for today's requirement would be to set up a mixed manufacturing system that can satisfy both MP and MC apparel orders with required flexibility.

Both the MP and flexible manufacturing technologies were discussed. The systems such as flow manufacturing that can be used to manufacture a product of one are appropriate for mass customization. But in a time of MP and high demand for customized products it is important to identify a mixed manufacturing strategy. In the line level, mixed manufacturing can be considered with two approaches. The ability to build mass-customized and standard products:

- in a single manufacturing unit
- dedicated lines in a single manufacturing plant

However, there can be a corporate hierarchy where mixing of MP and MC can take place at either or many of the following levels.

- Corporate
- Design
- Distribution
- Plant
- Line or work module

The ability to produce apparel on demand is the pay off for lean production programs. A spontaneous supply chain that can deliver parts and materials spontaneously without forecasts, purchase orders, part purchasing delays or warehoused inventory of parts and materials would facilitate the required on demand lean production (Anderson, 2002). In the literature it is often read that manufacturing systems such as flow manufacturing with a production batch size of one can facilitate build-to-order flexible manufacturing. Batch size of "one" refers to the smallest order quantity anticipated and the ability to manufacture this means that setup delays have been eliminated or reduced to a point that production can be efficiently carried out for the size of the order-on-demand without having to batch orders together to spread out the set up delays.

The set-up delays can be kit parts, find and load parts, position work pieces, adjust machine settings, change programs, set attachments, find and understand instructions, etc. Set-up elimination or reduction is highly required for mixed manufacturing to earn the cost advantages of MP and must be achieved with strategic approaches. For example, setting up for stitches per inch for product variability can be minimized by offering a specific stitch density for the customer or even remain without offering a stitch density but practice a feasible density in the manufacturing. Eliminating setup delays in programming or load programs to CNC machines is another approach. In apparel cutting operation this strategy can be used by using auto-marker making programs and directly loading the markers to CNC cutting machines. Planning well ahead in setting up for process variability can be achieved if product development and process development can be done concurrently to standardize on the variables that are time consuming to change. Designing garment parts and apparel categories to reduce set up is another strategy. Product family architecture is important in this aspect. Distribution of accessories such as different thread colors, various button types, etc. to all the stations that use help avoid kitting. The kitting is a setup which will inhibit flexibility. Another example in shirt manufacturing is to provide with all the collar sizes and shapes of interlining to the fusing station where the operator can select the appropriate one for a suitable style as demanded by the order. Engineering the workplace will also help reduce set-up delays.

Anderson (2003) discusses two types of lean production systems in general which are “replacement” and “spontaneous build-to-order” (Anderson, 2003). The common parts are built ahead of time and will be available for assembly in replacement lean production. As the parts are used, new parts are replaced may be using techniques such as kanban replenishment. Interlinings and common parts from standard materials such as collars, cuffs, pockets, etc. cut to shape can be considered in this aspect. Replacement lean production can be less applicable for high variability in demand such as in the higher end of the mass customization continuum and build-to-order lean production may need to be used as the remedial action. Dedicated production lines which may be of small capacities can be used to overcome setup problems. But it is also important to make sure that there are sufficient custom orders in comparison to MP orders. The smaller mixed production lines may not have the best utilization and line balancing but will enable to cater for the current needs in MC, customer satisfaction, competitive advantage, growth and profits.

In MP, each inflexible line has its own capacity, so the associated product output can only be increased by overtime, which is expensive and may not be sufficient. However, in a mixed manufacturing system this problem can be overcome as the flexibility is incorporated within the units and variety and demand peaks can be handled by the entire unit. Presently MP companies who attempt to move into the customization business face difficulties. Such as;

- The custom products and unusual standard products that need to be produced at low volumes are not making real profits as expected thus loosing money.

- The customized products need to be subsidized by the high volume 'cash-cows' which need to be priced higher to compensate the subsidization (Anderson, 2001)

The paper titled 'Mass Customization: Implementing the emerging paradigm for competitive advantage' argues that for firms competing in rapidly changing environments, the ability to maintain a sustainable competitive advantage depends on the firms capability to create knowledge by interacting both MC and MP approaches (Kotha, 1995). Therefore, Kotha's (1995) approach to mixed production focuses on the operational (internal) and competitive (external) aspects of pursuing MP and MC approaches simultaneously. This enables organizational knowledge creation and greater strategic flexibility. Further, Kotha (1995) provides a framework that illustrates the dynamics involved in pursuing both MP and MC strategies simultaneously. MC implementation involves major aspects of operations including product configuration, value chain network, process and information technology, and the development of a knowledge based organizational structure (Silveira et al., 2001)

2.4 SUMMARY OF LITERATURE REVIEW

Literature review of MP of apparel and the required flexibility towards the MC was discussed in detail. Apparel manufacturing system attributes comparison table is developed in defining the apparel manufacturing systems to be compared and used in the mixed MP, MC manufacturing simulation[1]. As MC means high level of variety suitable for individuals and as producing high level of variety for apparel products require high level of variation in production, an extremely high level of flexibility is required in the MC manufacturing system. For MC the production may need to be carried out with a lot size of one. There can be number of customization points in the apparel manufacturing process and there are many limitations to apparel MC. For MC to be effective, it must combine with the cost saving efficiencies of MP. Therefore, to obtain the cost benefits, the customized apparel may need to be manufactured within the MP manufacturing environment. Literature to support and define this combined apparel manufacturing system of MP and MC is not available. It is important to understand the benchmarking parameters and existing measures to identify the current practice of apparel manufacturing.

[1] See Chapter 6: Research Findings, Results and Discussion

CHAPTER 3

3 MEASURES FOR NEW PRODUCT DEVELOPMENT

The existing practice of MP and literature for MC were reviewed. It is important to study the benchmarking parameters for apparel manufacturing and the existing industry measure dimensions for apparel to identify existing abilities of moving from MP to MC or mixing MP and customized production. Therefore, a paper titled 'Measures for New Product Development" which addresses the existing measures for apparel, written and published by the author, is included in the Chapter 3 as the final part of the Literature Review. This paper was first published in detail in the Journal of Textile and Apparel Technology and Management and a more concise version was published in the Conference Proceedings of the 6th Asian Textile Conference (ATC) held in Hong Kong in 2001. The publisher granted permission to use the paper in this dissertation (Appendix F). The complete citation for the manuscript is given below (Senanayake & Little, 2001).

Senanayake, M. M., & Little, T. J. (2001). *"Measures" for new product development.* Paper presented at the 6th Asian Textile Conference - Innovation and Globalization, Hong Kong.

"Measures" For New Product Development

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ABSTRACT

Current measures for apparel product development are presented and described. The evolvement of the types of measurements is examined through the 1990's. The increase in the interest and changing emphasis in the area of product development is examined by analyzing the patent activity from 1971 to present. Published papers on the subject of textile and apparel product development show an increase throughout the 1990's. New trends, technologies and business practices are discussed in relation to the new era of product development competitiveness.

Key Words:
Product Development, Benchmarking, CAD, Digital Printing, Body Scanning, Rapid Prototyping, Whole Garment Knitting, Computer Integrated Manufacturing, Internet Commerce, Automatic Language Translation

1.0 Introduction

1.1 Product Life Cycle and Innovation

The development of new textile and apparel products is rewarding and this activity is necessary to sustain a profitable organization. A product undergoes a product life cycle of introduction, growth, maturity, and finally decline [5]. In the maturity or decline phase, an organization must take an active role to expand the apparel product line and either extend the apparel life cycle, re-align the apparel product to make it superior or develop a new apparel product to maintain revenue.

If new apparel products are not developed, sales and profits decline, technology and markets change, or innovation by other firms makes the original product obsolete. The resources needed for new apparel product development include R&D, engineering, and test marketing. Since all product ideas are not successfully developed and tested, substantial funds are spent on apparel products that never reach the market. The successful product must not only return its unique development cost but contribute to the development costs of unadopted or shelved products. The return on investment in new

apparel products will be attractive only if risks can be minimized and profits maximized. New apparel inventions, like any new product, are subjected to the high risk of failure and should be carefully evaluated before any major investment is made.
An apparel firm is continually aware of the marketing system and the macro-apparel business environment that impact on the organization. The firm learns to recognize factors in the market, which initiate new apparel products. The firm initiates new products because of financial goals, sales growth, competitive position, product life cycle, regulation, material costs, inventions, customer requests and technology.

Growth in sales is an important goal for many apparel corporations; in many cases it is absolutely necessary if profits are to be maintained. While sales growth is a continuing force for innovation, the emphasis has shifted to profitability as the prime concern [12].

1.2 Other Product Development Initiators

Governments are becoming increasingly involved in regulating apparel business. In many cases these new regulations cause apparel firms to consider producing new products. The regulatory power of government pervades competitive practices, advertising, product safety, labeling, labor practices, etc. As raw material costs and availability change, apparel products must be revised or dropped. In a world of increasing shortages and supply variability, the forecasting of supply prices and the development of new products to exploit the structural shifts in raw material price will be important in many organizations.
The postwar baby boom brought about market changes, including the rapid growth in apparel baby products, followed by the "youth" culture, overflowing colleges, and a very tight housing market. Life style, fitness and mass communication systems also generate apparel consumption shifts. Development of new apparel products to exploit these shifts will ensure the success of firms.

Other sources of new apparel product ideas are a customer request or a mass-customized demand to produce a specific apparel product that the customer has designed. In other industries, 80 percent of the major innovations were the result of customers who had a need to satisfy and built a prototype of what they needed [12]. It is common to think of the manufacturer as the innovator but suppliers can also be a force in innovation. A major factor accounting for the 'decline phase' of apparel products and the shortening of life cycles is the rapid change in technology. For firms who can be first to successfully create apparel products based on new technology, the rewards can be high. A proactive apparel firm follows these technological changes and puts them to profitable use by matching them to the changing market place.

2.0 Product Failure

The newly developed products can fail due to internal and external reasons:

2.1 External

- The failure may be due to a 'too small market'. A new product is developed that attains a large market share, but fails since the target market is not large enough to generate sufficient sales and profits.
- Due to the fact that the product does not display a 'new or different' feature, it can fail. The opportunity must be assessed in the design evaluation step to determine if consumers perceive the product as new and different. A product should be both physically and perceptually better than existing products.
- 'Competitive response' is another factor where competitors probably will copy the successful products. The best defense is to come up with a good design so as to preempt the competitors and earn its just reward.
- "Changes in consumers' tastes" are perhaps the most difficult problems to overcome in preventing a product failure. The dynamics of consumer tastes requires a continued monitoring process so that product can be redesigned, repositioned, dropped, or delayed.
- 'Change in environmental constraints' where new regulations, technology, and material supplies can cause failure to a new product.

2.2 Internal

- If the product does not agree with the company mission, it can fail. The market opportunity must match the company's strategic plan before development is begun.
- 'Misunderstanding of consumer needs' may be another factor for a product to disqualify. Also poor pricing is a cause for failure where the price/benefits positioning is not correct.
- 'Little support for the channel of distribution' can be an internal reason for a new product to fail.
- Many good products fail because of the poor organization of a firm. The main interests in R&D and marketing may prevent effective progress on a good product, while conflicts between the new products group and the sales organization may kill a good product.
- The issues of communication are serious and must be explicitly addressed in organizing for implementation of a new apparel product development process. Without clear responsibility, the best designed and tested product may fail due to poor execution of the introduction plans.
- 'Forecasting error' may be another reason for a product failure where the leading causes can be the over estimation of sales.

In conclusion the new product development process must be well defined, documented, broadly communicated, and understood throughout the firm which will obtain management's support for the project. An effective new product development process will reduce time-to-market through consistent execution of project team roles and responsibilities with the involvement of senior management at the appropriate points.

3.0 Changing Emphasis in the Area of Product Development

The level of activity in textile and apparel product development has been steadily increasing. This can be observed in terms of more styles for each company, global sourcing of additional styles to complement the existing line, and targeted development of products for target markets. Global sourcing has also increased the product development activity because of the advent of full package sourcing in addition to those products that are manufactured or sourced to specification. The increase in product development activity together with the global manufacturing and assembly practices, have integrated the product development more into the mainstream business decision structure of the firm. Product Development Measures being applied to today's products cover many aspects from the design concept to the consumer.

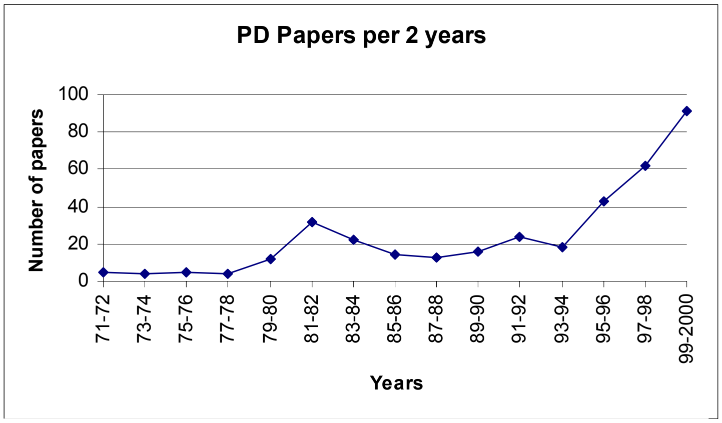

Figure 1 ***Source: World Textile Database (2001)***

As an overall measure of the changing importance of "product development", the number of published papers in the textile literature using the words "product development" were determined. This was accomplished by using the World Textile Database (2001) and its search engine. The results of this search are shown in Figure 1. Figure 1 shows that the number of published papers in the 1970's were less than 10 every two years. In the 1980's, the number of papers every two years were in the range of 13 to 32 and this publication rate continued through 1993-94. However, after 1993-94, the number of publications devoted to product development has increased significantly. In fact, the data shows a three to four fold increase in the number of publications related to product development.

Furthermore, in reviewing the number of patents issued for product development related technologies, it can be seen from Figure 2 that the number of patents has increased significantly in the 1990's. More importantly is the fact that the number of patents issued to product-related technologies has increased significantly over the past four years compared with the patent activity for the previous 25 years. Patent issue rates for product development activities have reached an annual average of 32 per year compared with an annual rate of 2-13 per year for the years of 1971 – 1996. Figure

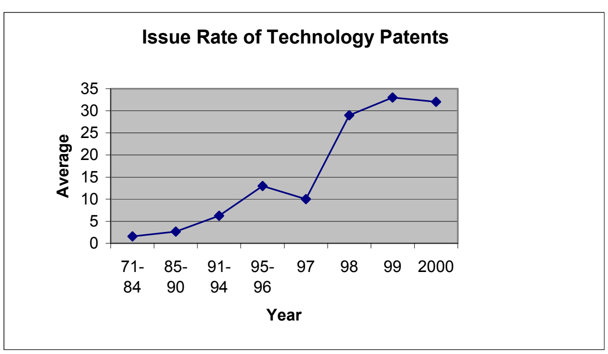

Figure 2 ***Source: U.S.Patents (2001)***

3 shows the breakdown of patents by major product development technology.

This data clearly shows that the last five to six years have been dominated by patents related to rapid prototyping, computer aided design and digital printing. It is of interest to note that five recent patents (1998, 1999, and 2000) have been issued for product development and this may signify the start of a new category of patents related to the entire subject of product development. The U.S. Patents (2001) and its search engine were used to determine the results in Figures 2 and 3.

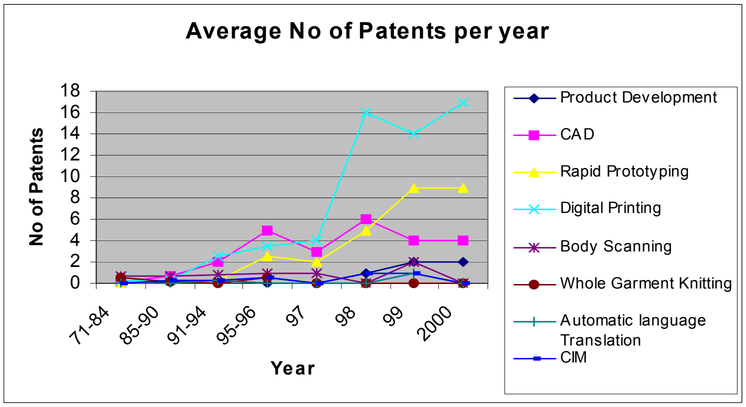

Figure 3 ***Source: U.S.Patents (2001)***

4.0 Product Development Models

The models of the new product development process are helpful to look at in detail the stages and activities in the product development process. The published product development models for apparel are of a sequential type. Some of these models define the process with general stages and others use list of activities. The models created by Burns and Bryant (1997), Regan, Kincade and Sheldon (1998), and Sadd (1996) describe the process as a series of stages in a linear progression following the form of the traditional sequential model. In 1992, Gaskill incorporated internal and external factors to her apparel product development model. Wicket, Gaskill and Damhorst (1999) tested and expanded the Gaskill's 1992 model beyond line presentation to include events and considerations in post adoption product development creating a revised retail apparel product development model [14]. May-Plumlee and Little (1998) developed the No-Interval Coherently Phased Product Development Model for apparel, which is a six-phase apparel product development model. This model indicates the involvement of four functional areas Marketing, Product Development, Merchandising and Production Planning and Control. This model includes functional overlaps and recycling ideas through previous development phases for further refinement. The in-depth examination of each phase of the development process has been explained using six stages with detailed explanations of each [7].

5.0 Benchmarking the New Product Development Process

Benchmarking is a formalized approach to business improvement and is an effective tool to facilitate improvements in all areas of operations, including product development. It guides the firms to focus on areas of greatest weaknesses and allows companies to prioritize their efforts and improvement to be measured. The parameters, which are used to benchmark, are discussed below.

- **Sample Adoption Ratio:** Sample Adoption Ratio is the percentage of product development samples that are actually adopted into a line and indicates how efficiently the product development process functions. Sample adoption ratio in 1994 typically measured at 20% to 30% for fashion products and 40% to 75% for basic and fashion-basic products [10]. Companies that have conducted well-focussed improvement programs have suggested that the Hit Ratio is about 50%, and the percentage of concepts used in the final line as 30 percent [9].

- **Seasons Per Year:** Selling seasons are the number of clearly differentiated (by styling, fabric weight, or other factors) selling seasons in a year. This provides an indication of how often new lines are presented. The concept of buying/selling seasons may be eliminated as manufacturers and retailers respond to the individual demands of each customer.

- **Product Development Cycle Time:** Product Development Cycle time is the time between designer's concept and when the style is released for production. As the number of line seasons increase, and as the diversity of most product lines expand, the need to shorten the time required to develop new products becomes more important. Product development cycle times in the one to three months range are achievable for fashion garments and in the three to four weeks range for basic garments [10]. It is not only a product development measure but also a measure of merchandising excellence. This product development cycle reduction can allow for more fashion seasons, lower product development costs, and significantly increased competitiveness. The companies, which focussed on improvement programs, have suggested that the cycle time for basic styles and fashion styles (from concept to pre production sample) is 30 to 60 days and 3 months respectively [9].

- **Manufacturing Cycle:** This is defined as the time between receipt of an order and the time when the order is shipped to the customer. This measurement shows the effectiveness of the production end of an apparel company's business.

- **Sell Through:** Sell Through is the percentage of product that is sold at retail at regular price. Increasing sell through is critical to increase profitability and competitiveness. The marketing and merchandising present the product line to sales and educate the sales force to sell the line according to the merchandising plan. Therefore, this is also a measure of line presentation success [1]. More fashion-oriented products tend to have lower sell through, typically in the 20-40% range and basic-oriented products yielded a higher rate of approximately 45-50%. If a product was positioned by the retailer as a promotional vehicle, or had a proliferation of stock keeping units (SKUs), the sell through performance could plunge to 25% or less. It was not until e-commerce emerged that manufacturers could easily access and review the last season's performance with the consumer [10].

- **Pick and Ship Times:** This is defined as the time between the receipt of a picking ticket in the distribution center to the time the product is shipped. This benchmark indicates the effectiveness of the distribution center.

- **Initial Forecast Accuracy and Forecast Accuracy:** The line plans can be evaluated according to the initial forecast accuracy. That is, wholesale orders placed as a percent of demand projected when a style or merchandise group is accepted in the line. The Forecast Accuracy is the ratio of actual order demand to the forecasted order demand expressed as a percentage.

- **Finance:** If the structure of the soft goods industry evolves as projected, the overall financial performance of all members of the chain will improve significantly. However, major investments in time, technology and systems will be required to make this happen. To support future investments required for improved profitability, better profit performance is necessary in the entire product development process. Some of the finance measures used in the apparel industry are Gross Margin (GM) and Gross Margin Return on Investment (GMROI), Return on Equity, Return on Net Assets and Investment per Sales Dollar [1].

- **Order Fulfillment Efficiency**: Order Fulfillment Efficiency (OFE) is the percentage of orders that are filled exactly as placed and defined by the customer. It is a measure that computes performance from receipt of a customer order until the order is shipped as complete [1]. This measure is becoming more critical as fulfillment requirements are tightened by retailers.

- **Textile Inventories and Inventory Turns:** The average amount of yarn or fabric inventory in-house, expressed in days or weeks represent the Textile Inventories. Inventory Turns is the ratio of cost of goods sold to the average of the beginning and ending levels of total inventory. This benchmark indicates how long a company holds an average item of inventory before it is sold. In other words it is the number of times the manufacturer uses its average raw materials, finishes its average work-in-process, and ships its average finished goods inventory in a period. As with the textile order cycle time, increasing linkages between apparel and textile companies are driving a decrease in “in house” textile inventory levels. Too long in inventory will result in high carrying costs while too short in inventory can mean loss of sales.

- **On-Time Delivery:** This is defined as the percentage of orders placed that are actually delivered to the customer within that customer’s delivery timetable and expectations.

- **Order Replenishment Cycle:** Order Replenishment Cycle is the time between receipt of a replenishment order from a customer to the time the replenishment product is received by the customer. In a retail environment, which emphasizes replenishment capability over maintaining high levels of inventory, the benchmark category is critical, particularly in commodity products.

- **Customer Order Processing Time:** This is the time between receipt of a customer's order and its entry into an organization's systems for action. Technology and process optimizations are the keys to reducing this time to a minimum.

- **Finished Goods Inventories:** This is defined as the average amount of finished product inventory in-house, expressed in days or weeks. The level of finished goods inventory should be adequate to support order fulfillment efficiency requirements.

- **Textile Order Cycle:** The Textile Order Cycle is the time between placement of an order for yarn or fabric and actual receipt of the yarn or fabric. This benchmark is an indication of the degree of integration that has been achieved through linkages and electronic commerce.

- **SKU Planning Frequency:** This measure relates to how frequently a firm plans production as a reaction to changes in forecast or in order demand. The frequency can be monthly, bi-weekly, weekly or daily [1].

- **Time from Plan to Cut:** This measure is the time from SKU planning until cutting is completed and the cut is ready to go in to the work-in-process inventory. The idea of this measure is to assure accurate replenishment of the finished goods inventory.

- **Shipping Cycle Time:** This measures the time from an order being released to ship until it is released to the carrier to be delivered to the customer.

- **Shipping Accuracy:** A measure of number of units shipped in the correct style, color and size as a percentage of the total units shipped.

- **Other Measures:** New measures for retail logistics, retail inventory management, EDI and Bar Coding have evolved. Little and Heinje (1998) discussed 3 measures on Retail Logistics, 6 measures on Retail Inventory Management and 5 performance measures on EDI and Bar Coding. In addition, it is of great need to develop measures for electronic commerce business in terms of product development. This is to benchmark the total apparel organization today rather than measuring the PD process in isolation. This is of great importance, as the new product development activity needs communication to all the functions in an organization.

6.0 Quantifying the Extent of System Integration:

Systems integration will require examinations of all processes not just focused inspection of specific problems. Systems are the key to all other competitive improvement opportunities. Without the synergies of integrating all processes from design through delivery, the firm will not have the responsiveness required to have a sustainable business. An effectively integrated system will tie together all the functions in an organization. To date the authors are not aware of any measures to assess the level of system integration.

7.0 PD Measures and Measures for Getting the New Products to the Customer.

It can be clearly seen from Table 1 that the number of measures involved in the product development process has increased over time, with the measures becoming more stringent. This reflects the industry's increased focus in monitoring the PD process. The measures for getting new products to the customer, as shown in the Table 2, also have increased remarkably over time [6]. For example, according to the Measures for Excellence report by the Quick Response Leadership Committee of AAMA, there were 31 measures discussed in 1996 and more than 40 measures discussed in 1998.

Product Development Measures

Table 1.

	Best in class measures										
	Sample Adoption Ratio (%)	PD Cycle Time (weeks)	Manufactu-ring Cycle Time (weeks)	Sell Through (%)	Pick and Ship Time (days)	Return on Equity (%)	Return on Net Assets (%)	Investment per Sales dollar (%)	Forecast Accuracy (%)	GMROI (%)	Cost Confirmance (%)
[2]	60	3 (2 to 6)	20(5-50)								
		months	days								
[10]											
Apparel Type											
Blazers & Jackets	25	16	3	25	3	25	22	2			
Bras	75	12	1.5	80	2	18	16	2			
Dress Shirts	60	6	1	50	1	20	25	2			
Dress Slacks	30		3	60	3	25	22	2			
Dresses	35	16	3	30	3	25	22	2			
Jeans	50	5	1.5	60	1	30	40	2			
Ski Jackets	60	15	5	85	2	22	20	2			
Socks	60	6	2	60	2.5	21	19	2.5			
Suits	35		5	65	3	25	22	2			
T-shirts	90		2 days	85	2	16	11	2			
[6]		30 days	1	95					85	31	120

Getting New Products to the Customer

Table 2.

	Best in class measures										
	Order Full-fillment Efficiency (%)	Textile Inventories (weeks)	Inventory Turns (ratio)	On time Delivey (%)	Order replenish-ment Cycle (days)	Customer Order Processing Time (days)	Finished Goods Inventory (weks)	Textile Order Cycle Time (weeks)	Floor Ready Shipments %	Auto Replenishm-nt Shipments %	Retail Logistics 3 measures
[2]	85	3 to 5	3.75								
[10]											
Apparel Type											
Blazers & Jackets	90	6	4.2	94	3	2	8	12			
Bras	95	8	7.5	95	7	2	2	10			
Dress Shirts	92	2	6	92	7	0	5	4			
Dress Slacks	96	6	3.5	99	3	1	7	13			
Dresses	90	6	4.2	93	3	2	7	12			
Jeans	96	2	6	95	1	0	4	3			
Ski Jackets	92	8	3.5	94	7	1	4	10			
Socks	93	1	5	98	4	2	8	2.5			
Suits	95	6	3.5	99	3	1	10	13			
T-shirts	95	1.5	8	95	3	0	3	1			
[6]	99		7.5	99	2				100	80	

The reason for evolving more company-wide measures can be suggested as integrating the product development process in to the company strategy. Some of the other measures, which have not been shown here are performance measures, related to retail electronic data interchange (EDI) and Bar Coding practices which were considered later as benchmarking parameters for the apparel industry. With the evolvement of virtual technologies [11], it is required to develop more and more measures to benchmark the product development process such as performance of virtual samples, quality of virtual samples etc.

8.0 Changes Anticipated

Apparel manufacturers have concentrated efforts to reduce manufacturers cycle time and cost. However, the revolutionary nature of the apparel environment today is forcing manufacturers to examine pre-production processes and ways to eliminate non-value-adding elements. The compression of the typical calendar is underway, although many apparel manufacturers still maintain product development cycles with as many as 40 distinct steps requiring as long as six months. To reduce leadtimes and improve flexibility and responsiveness, more textile and apparel firms are forming strategic alliances. Some apparel companies are developing internal textile capabilities or moving operations near key supply locations. Benchmark companies are achieving product development cycle times in the range of five to six weeks. With the number of SKUs per season typically increasing, and with retailers demanding shorter leadtimes, the margin for error in product development must decrease. Technology needs to be implemented with an integrated approach to optimize the success rate of new products. Therefore, benchmark companies are implementing structural and technological improvements designed to reduce this risk and improve customer focus. Market research and analysis for benchmark companies is focused, structured and formalized. There is increasing use of consumer panel data, focus groups and in-store testing. Companies will move towards a seasonless operating mode, where merchandising and product development will be done continuously.

9.0 Summary

The Product Development function in the textile and apparel industry appears to be gaining activity as we examine the measures of recent progress represented in Patents and Papers. The increasing number of product development measures and technology improvements will lead to new competitive practices in product development. A new challenge will be to develop appropriate measures to identify the extent of system integration and how to measure the effectiveness of the virtual product development methodologies being used to create new products.

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CHAPTER 4

4 RESEARCH OBJECTIVES AND HYPOTHESES

4.1 The Research

As mass customization business model gains recognition in the apparel industry, companies have various approaches to manufacture customized apparel for the demand. Build-to-order customized apparel manufacturing is increasingly in demand. As the name implies manufacturing customized apparel to achieve the cost benefits of mass production is the expectation for MC. Many companies who manufactured MP apparel for the mass market are trying to incorporate customized apparel in their business models. It is therefore important to see how the transition and mixing of MP and MC can take place. It is also a question of whether manufacturers can produce both MP and customized apparel in the same manufacturing units or are they required to produce them in separate production units. Another research objective is to identify at what point of its growing MC business a company must make a decision to move to a separate MC production system. The research leads to an understanding of the requirements for MP and MC apparel manufacturing and specifically focuses on identifying whether customized apparel can be manufactured with MP in a mixed manufacturing system. To explore the opportunities further, the author's research is to investigate the existing industry practice on MC apparel manufacturing.

At the introduction stage in Chapter One, a series of research questions was presented as the foundation for the research. These questions centered on the perceptions of the apparel industry participants as to the emerging MC business practice. Specifically, the questions of interest were to identify how customized apparel manufacturing can be achieved at mass production efficiencies and whether customized apparel could be manufactured in a mixed manufacturing system using existing MP manufacturing systems. These research questions are converted into the hypothesis in the following paragraph.

4.1.1 Hypothesis 1

Important parameters that exhibit various capabilities of existing MP apparel manufacturing systems suggest that they can be used in the customized apparel manufacturing process. The flexible manufacturing systems with flow, lean and synchronous strategies have evolved over time to cater for manufacturing variety. The concepts such as QR and JIT became important to supply goods on short leadtimes in small lots of high variety SKU's and is practiced as business models. Based on these reasonings it is expected that the customized apparel can be manufactured by MP in the MP manufacturing systems as a mixed system which is the expectation in the hypothesis.

- H1: MP and MC mixed manufacturing of apparel can be done in the same production unit.

4.1.2 Hypothesis 2

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 various needs demanded over time. The assembly technology continues to be refined with new technology developments emerging at a rate of more than 100 inventions per year which includes both sewing and supporting technologies[1]. 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 capable of handling MC apparel manufacturing that supports the hypothesis:

- H2: Technological advancements in apparel assembly and innovations in supporting technologies have taken place which support MC apparel design, ordering and execution.

4.1.3 Hypothesis 3

The literature reviews other industries such as bicycle manufacturing that started separate manufacturing units for MP and customized manufacturing as the customized business increased. This is an example for a MP becoming a custom production system. For apparel manufacturing the feasible practice was to have separate production lines for different styles and it was never seen as manufacturing high variety styles in the same line. With this limitation in effect it must be noted that the following hypothesis suggests a MP model will become a MC manufacturing business model.

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[1] See Chapter 2: Apparel manufacturing supporting technologies vs. assembly technology

- H3: The MP is becoming custom production. In other words as the number of MC orders grow it mandates a dedicated manufacturing system for the customized manufacturing.

4.1.4 Hypothesis 4

As the variation of the product gets larger the setup times and other manufacturing complexities exceed the system abilities. As the extent of customization moves from standardization towards customization in the MC continuum, the Points of Customization demand a flexible manufacturing system to overcome variety complexity. Therefore, the following hypothesis address this issue suggesting that the Points of Customization and the Extents of Customization play a major role in the mixed MP and MC manufacturing.

- H4: The Points of Customization and the Extents of Customization are important factors in the process of mixed MP and MC apparel manufacturing.

The following Points of Customization are defined.

4.1.4.1 Points of Customization

- Design Customization: DCP

Design Point of Customization addresses how the customer is given the opportunity to design the apparel product. Within this Point of Customization there can be varying Extents of Customization such as allowing the customer to design the product with no limits or the options may be restricted so that manufacturing task can be achieved with less complexity. In the existing MC business practice the customer may not be given full control over the design but only a few features of the design. This DCP can affect the entire process of MC.

- Fabrication Customization - FBCP

Fabrication Point of Customization addresses how the customer is provided with the choice to decide on the materials within the existing product category. As explained above, the Extent of Fabrication Customization may affect the manufacturing operation thus needs to be limited as needed. This point will affect primarily the pre-production stage of the MC process.

- Fit Customization - FTCP

Fit Customization can be defined as the flexibility offered to the customer to decide on the measurements needed, the general fit ease and silhouette. The Extent of Fit can be varied with few measurement options or fit options offered to the customer to obtaining the full body measurements from the customer. Fit Customization Point affects the MC manufacturing process at the pre-production stage, especially at the pattern making stage.

- Feature Customization - FRCP

Feature Customization defines the Point in the MC process where the customer has the options to select or define features. The Extent of Feature Customizations may provide the customer the power of demanding features or accepting the offered features.

This Point of Customization can affect the MC manufacturing process in both pre-production and assembly.

- Post Production Customization - PPCP

This Point of Customization customizes apparel after the production process. Post Production Customization can provide customers customized apparel after manufacturing or from mass produced stocks. The Extents of this point of customization can be features such as monogramming, logos, emblems, printing, etc.

4.1.5 Hypothesis 5

In the MP strategy, retailers proliferate the market with variety, in effect pushing the variety into the market and anticipating the demands of the customer. While the customer can choose from a mass of products, there is no integration into the manufacturing and design processes. The customer's only input is to purchase or not to purchase. In contrast, with MC, the customer may be involved with the conception of the product, with its design, and working with the designers to best meet the needs of the consumer. The stages or path between these two ends defines the Extent and Points of Customization. The manufacturing of mass-customized apparel demands complete understanding of these Points and the Extent of Customization. It is important to understand the extent of customization in the continuum from MP to MC for manufacturing customized apparel so that manufacturers can make decisions based on where they stand in the continuum. How does the point of 'custom' move in the continuum and how the continuum of customization linking MP to 'custom' are important questions that can be raised by manufacturers. These circumstances lead to the following hypothesis:

- H5: The MC continuum is not a linear model.

4.1.6 Hypothesis 6

Tracking and identifying the individual customer order in the mixed MP and MC manufacturing environment become of paramount importance for various reasons. From the customer end, an inquiry can be made to seek the status of the individual order. When processing the customized order in a MP environment, the manufacturer needs to differentiate the orders as well as supply sufficient information to the operators for product identity. It is extremely important to identify the orders in individual garment form and not as in a batch form. Therefore:

- H6: The order tracking system should be technologically advanced in the mixed manufacturing model.

4.1.7 Hypothesis 7

Benchmarking information for the existing practice of MP is also very important to identify the capabilities of the apparel manufacturing systems that will be used to mix MP and customized apparel for MC. Measures such as manufacturing and product development cycle time, on-time delivery, order replenishment cycle, etc. can be used to compare the existing practice and requirements in MC so as to identify strategies to achieve success in mixed manufacturing

- H7: Benchmarking product development from concept to manufacturing apparel is important to identify the existing practice of MP.

The Table 4.1 provides a summary of the seven hypotheses of the proposed research, cross referenced with the methodologies proposed to test the validity of the hypothesis. Additions for proposed methodologies were made as a result of the discovery process.

4.1.8 Methodologies to Test Hypotheses

I. Literature Review

II. Case Study

III. Computer Simulation

IV. Industry Survey

V. Personal Communication with Consultants

Table 4.1: Hypotheses and methodologies

Hypothesis	Methodology
H1: MP and MC mixed manufacturing of apparel can be done in the same production unit.	I III, IV, V
H2: Technological advancements in apparel assembly and innovations in supporting technologies have taken place which support MC apparel manufacturing.	I, V
H3: The MP is becoming custom production. In other words as the number of MC orders grow bigger it is suitable to have a dedicated manufacturing system for the customized manufacturing.	I, II, III
H4: The ability to efficiently mix MP and MC in the manufacturing will depend on the extent of customization that depends on the points of customization.	IV, V
H5: The MC continuum is not a linear model.	I, IV
H6: For operations aspect the order tracking system should be technologically advanced in the mixed manufacturing model.	I, II, V
H7: Benchmarking product development from concept to manufacturing apparel is important to identify the existing practice of MP and MC.	I, IV

CHAPTER 5

5 METHODOLOGY

Mixed MP and MC apparel manufacturing systems are researched using several methods. Computer simulation is used to investigate the quantitative issues of mixing MP and MC in different production systems. An Industry Survey instrument is used to benchmark current industry practices. Personal Communication with academics, industry experts and consultants who are involved in MC of apparel and a Case Study Analysis of a current MC operation represent the methods discussed in detail. The reviewed literature is used to develop information models that are used to design the research methods.

- A comprehensive apparel manufacturing system attribute comparison table was developed that is used to design the mixed apparel manufacturing simulation model.
- The Points of Customization that were discussed in the literature by various authors for various industries are analyzed and compared with the information obtained as a result of the research methods in finalizing a proposed set of Points of Customization for apparel. The linearity of the customization continuum is investigated using one of the models discussed in the literature.
- The system needs and the supporting technology infrastructure that supports mixed MP and MC apparel manufacturing is investigated.
- The principles and techniques for apparel mass customization and their applicability to apparel with examples is explored.

These findings are illustrated in Chapter 6.

5.1 RESEARCH DESIGN

No empirical research has been carried out on mixed MP and MC apparel manufacturing thus a portion of this research is to explore new areas. A multiple method approach was used to gather qualitative and quantitative information using the methods as shown in the Figure 5.1. This approach was considered useful to generalize the findings to a population set, and to establish meaning of phenomenon or concept for individuals (Cresswell, 2003). By choosing the multiple method approach combined with simulation, the benefit is that the final knowledge base represents both qualitative and quantitative information.

Survey methodology was used to gather industry practice information on apparel categories, customization, extent of customization, manufacturing, distribution, and costs. Interviews with MC experts provided more in-depth information to the knowledge base. A Case study approach allowed collecting a greater breadth and depth of data relevant to industry practices. The results from computer simulations were correlated and compared to enhance the knowledge base in mixed MP/MC manufacturing.

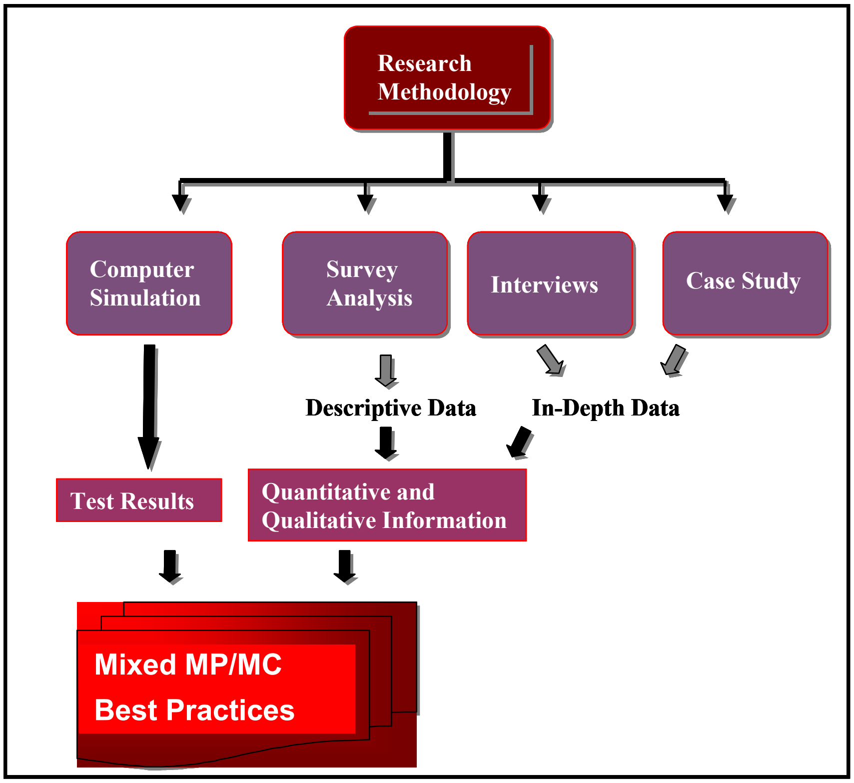

Figure 5.1: Research methodology

In addition to the above multiple method approach, the literature was critically reviewed to understand the approaches, extents, points, principles, and techniques of customization. Proposed approaches to customization for apparel were developed and will be explained in Chapter 6.

5.2 Research Methods

For the mixed MP/MC simulation model, a shirt-manufacturing unit is simulated using data from a company that practices both MP and MC of apparel. This company also participated in the Case Study.

A single company that practices both MP and MC was selected to obtain input data and validation information for the mixed MP/MC simulation model based on the company's expertise in mass production and mass customization. For the Survey, Case Study and Personal Communication methods, companies selected were chosen because of their ongoing mass customization practices.

24 companies were selected for the Industry Survey. The criteria for the sample selection process for the Survey included:

- Sector – Apparel
- Companies operating in the above sector that practice apparel mass customization to whichever extent for the United States market
- Manufacturing can take place inside or outside the United States

The most qualified persons to answer the survey was identified and contacted prior to mailing the Survey. Personal communication (Interviews) consisted of four consultants out of which three are decidedly attached to the apparel industry and one was an expert in build-to-order and mass customization. Three companies (who also participated in the Survey) agreed to the additional Case Study method.

5.2.1 Computer Simulation of Mixed MP/ MC Apparel Manufacturing

Shirt manufacturing was simulated using the $[TC]^2$ TeamMate® apparel production simulation tool, which was developed by the Textile and Clothing Technology Corporation $[TC]^2$ in Cary, North Carolina (Textile-Clothing-Technology-Corporation, 1998). The Feature Customization[1] was considered for the mixed manufacturing with monogramming operation as the customized operation in the mass-customized shirt manufacturing process. The simulation tool was critically analyzed to be able to use for the research. Even though there can be various extents of customization under the Feature Point of Customization, only one operation in the process was considered as customized in the simulation. The knowledge of the apparel manufacturing system attributes, apparel MP, available technologies and approaches to mass customization that was gathered as a result of the critical literature review assisted in modeling the mixed MP and MC apparel manufacturing. The operational characteristics of the simulation tool are discussed in detail in the Appendix B. The information provided is from the manual of the simulation tool and the experience gathered by extensively using and adapting the tool to achieve research objectives.

5.2.1.1 Mixed MP/MC Simulation Models

The effect of introducing customized apparel to the MP manufacturing environment was investigated using a Progressive Bundle System as the starting stage. Secondly, mass produced apparel was introduced to a mass-customized Kanban Production system. This Kanban line was further analyzed by modeling the line as a MP system and introducing customized apparel to explore the effect.

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[1] See Chapter 4: Points of Customization

5.2.1.1.1 Strategy 1: Moving from MP Product to MC Product - Integrating MC Product into MP System

As shown in Figure 5.2, the manufacturing process started from MP product towards customized product direction capturing the effect of Mass Customization. It must be noted that the extent of customization considered for the product was limited to the extent that it does not reach the fully customized zone.

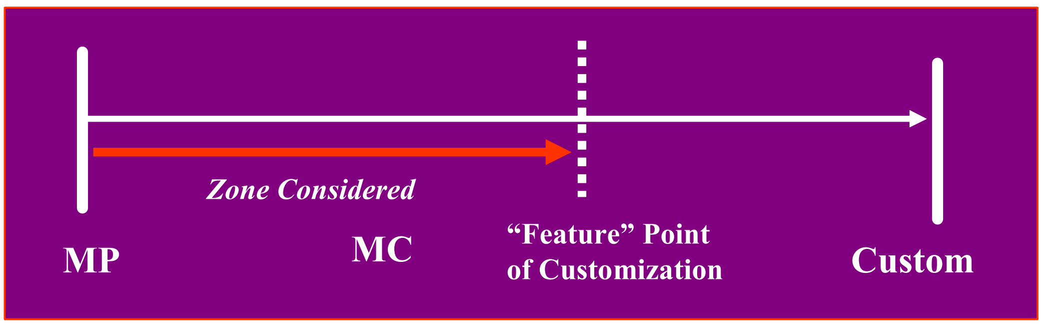

Figure 5.2: Moving from MP product to MC product for Feature Customization

A Progressive Bundle System was selected as the MP manufacturing system, which was modeled for simulation as this manufacturing system has been long utilized in the global apparel industry for MP of apparel. The research objective of this experimental simulation was to learn how a Progressive Bundle manufacturing unit behaves when mass-customized clothing was introduced with increasing volume or frequency.

5.2.1.1.2 Strategy 2: Moving from Mass-customized Product to MP Product - Integrating MP Product into MC Manufacturing System

As shown in Figure 5.3, the manufacturing process started from customized apparel towards MP product capturing the effect on MC line performance. The research objective of this experimental simulation was to learn how a UPS behaves when the MP product was introduced with increasing volume or frequency.

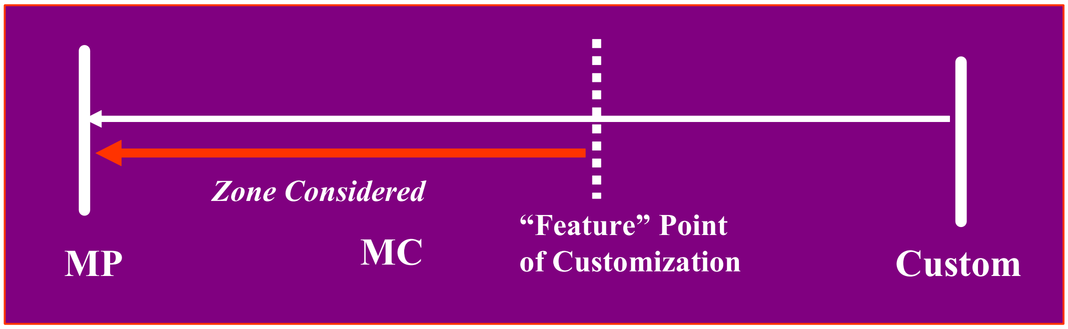

Figure 5.3: Moving from MC product to MP product for Feature Customization

5.2.1.2 Adapting the Simulation Tool for Research Expectations

5.2.1.2.1 Data Collection and Analysis for Simulation

A plant visit was made to an apparel manufacturing facility, which practices both MP and mass-customized shirt manufacturing. Apart from obtaining data for the computer simulation, a Case Study was also developed[1]. Following the plant visit, constant communication was made with the production engineer to obtain data for simulation model building and results verification. The company uses a Progressive Bundle System for MP and a Unit Production System for mass-customized shirt manufacturing. The processing times for a mass-produced and a mass-customized shirt style were obtained and documented. The monogramming operation on shirt pocket was considered as the customized operation in the mixed MP, MC manufacturing process.

[1] See Chapter 6 – Research Findings, Results and Discussion

This is referred to as Feature Customization in the dissertation, which was built-in to the operation at the assembly point of customization. The MP shirt manufacturing has all the operations other than the customized monogramming operation. The operations sequence and its breakdown for the shirt manufacturing process was critically studied. The next section discusses how the simulation was designed for strategies discussed above.

5.2.1.2.2 Strategy 1: Integrating MC Product into MP System – PBS

The production system that was simulated is a Progressive Bundle system with concurrent operations of major sections such as collars, cuffs, sleeves, fronts, yokes and backs. These were sub-assembly processes that were used for the assembly operation. The operators were considered stationary at their workstations and not moving between operations as is usual in a Progressive Bundle System.

The operation breakdown for the MP shirt style is shown in Table 5-1. Due to confidentiality the SAM values are not disclosed. As it was required to identify a good line balance with good line efficiency, the number of operators required and their efficiencies for various production quantities per day were analyzed by developing an Excel spreadsheet instrument as shown in Table 5-2. The highest number of workstations with operators, each that had efficiency between 90% - 110%, was selected as shown with gray color cells and totals were calculated. Production quantity of 3000 units per day was selected with 33 stations within the efficiency range. The stations which had efficiencies outside this range were limited within 85% - 125% and the line was balanced as shown in the Table 5-3. After running the simulation it was found out that the line had only about 84% efficiency and the bottle neck points could be the stations that had efficiencies outside the range of 90-110%. The monogramming operation which was considered as the customized operation, and the processing time for the operation, was also included at the appropriate point of the sequence which was used to balance the line for customized shirt styles. As the monogramming operation was not carried out for all the shirts but for customized units, it was not balanced for 3000 units. As the average number of customized shirts per day was about 100 shirts this operation was balanced with one operator. This Table also provides the operator numbers, station numbers, and individual operator efficiencies which were required to model the production line using the simulation tool.

Table 5.1: MP operation sequence for men's long sleeve pinpoint button down collar, single pocket, barrel cuff shirt.

Op. No.	Operation
1	Auto Make Collar
2	Turn,Press Topstitch Collar
3	Trim and Notch Collar
4	BH Collar Points
5	Hem Square Band
6	Band Collar
7	Turn,T & E Band
8	Beadstitch Band
9	Trim Band
10	Notch Band
11	Hem Button Front
12	BS Button Front Auto
13	Run Topcenter Auto
14	BH Front Auto
15	Examine,Trim and Pair Fronts
16	Auto Hem Pocket
17	Set Pocket-Solid
18	Hem Cuff Auto
19	Make Cuff Auto
20	Turn and Press Cuff
21	Topstitch Cuff
22	BH Cuff
23	BS Cuff
24	Set Wide Sleeve Facing
25	Set Narrow Sleeve Facing
26	Block Sleeve Facing
27	T & E Sleeve
28	Sew Label to Yoke
29	Bartack Yoke for Pleat
30	Manual Yoke w/Center Pleat
31	Join
32	Set/Close Collar
33	Mark Buttondown Buttons
34	BHBS Band,BS Buttondown Buttons
35	BS Extra Button on Front
36	1st Sleeve
37	2nd Sleeve
38	T & E after Sleeve
39	1st Fell
40	2nd Fell
41	Set Cuff
42	Hem Bottom
43	Final T & E
44	Collar Press
45	Front Press
46	Fold Long Sleeve

Table 5.2: No of operators to produce given production volume per day and total workstations with efficiency 90%-110%

Op. No.	Operation	No of operators required to produce the volume per day / Production Volume (Number of Shirts) 500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000
1	Auto Make Collar	0.3	0.6	0.9	1.1	1.4	1.7	2.0	2.3	2.6	2.8	3.1	3.4
2	Turn,Press Topstitch Collar	0.5	0.9	1.4	1.8	2.3	2.7	3.2	3.6	4.1	4.5	5.0	5.5
3	Trim and Notch Collar	0.2	0.4	0.7	0.9	1.1	1.3	1.6	1.8	2.0	2.2	2.5	2.7
4	BH Collar Points	0.2	0.3	0.5	0.6	0.8	1.0	1.1	1.3	1.4	1.6	1.7	1.9
5	Hem Square Band	0.3	0.7	1.0	1.4	1.7	2.0	2.4	2.7	3.0	3.4	3.7	4.1
6	Band Collar	0.8	1.5	2.3	3.1	3.8	4.6	5.3	6.1	6.9	7.6	8.4	9.2
7	Turn,T & E Band	0.5	1.1	1.6	2.2	2.7	3.3	3.8	4.4	4.9	5.4	6.0	6.5
8	Beadstitch Band	0.5	0.9	1.4	1.8	2.3	2.7	3.2	3.6	4.1	4.6	5.0	5.5
9	Trim Band	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
10	Notch Band	0.2	0.3	0.5	0.6	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8
11	Hem Button Front	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.5	1.7	1.9	2.1	2.3
12	BS Button Front Auto	0.2	0.3	0.5	0.6	0.8	0.9	1.1	1.2	1.4	1.6	1.7	1.9
13	Run Topcenter Auto	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
14	BH Front Auto	0.2	0.4	0.6	0.9	1.1	1.3	1.5	1.7	1.9	2.2	2.4	2.6
15	Examine,Trim and Pair Fronts	0.9	1.8	2.7	3.6	4.5	5.3	6.2	7.1	8.0	8.9	9.8	10.7
16	Auto Hem Pocket	0.1	0.3	0.4	0.6	0.7	0.9	1.0	1.1	1.3	1.4	1.6	1.7
17	Set Pocket-Solid	0.3	0.5	0.8	1.1	1.3	1.6	1.9	2.1	2.4	2.7	2.9	3.2
18	Hem Cuff Auto	0.3	0.5	0.8	1.0	1.3	1.6	1.8	2.1	2.4	2.6	2.9	3.1
19	Make Cuff Auto	0.3	0.7	1.0	1.3	1.7	2.0	2.4	2.7	3.0	3.4	3.7	4.0
20	Turn and Press Cuff	0.3	0.6	0.9	1.1	1.4	1.7	2.0	2.3	2.6	2.8	3.1	3.4
21	Topstitch Cuff	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.5	2.8	3.1	3.4	3.7
22	BH Cuff	0.2	0.5	0.7	1.0	1.2	1.5	1.7	1.9	2.2	2.4	2.7	2.9
23	BS Cuff	0.2	0.3	0.5	0.6	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8
24	Set Wide Sleeve Facing	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.6	5.1	5.6	6.1
25	Set Narrow Sleeve Facing	0.5	0.9	1.4	1.8	2.3	2.7	3.2	3.6	4.1	4.5	5.0	5.4
26	Block Sleeve Facing	0.9	1.8	2.7	3.6	4.5	5.4	6.3	7.2	8.1	9.0	9.9	10.8
27	T & E Sleeve	0.5	0.9	1.4	1.8	2.3	2.7	3.2	3.6	4.1	4.5	5.0	5.5
28	Sew Label to Yoke	0.7	1.4	2.0	2.7	3.4	4.1	4.7	5.4	6.1	6.8	7.4	8.1
29	Bartack Yoke for Pleat	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	1.9	2.1	2.3
30	Manual Yoke w/Center Pleat	0.7	1.3	2.0	2.7	3.3	4.0	4.7	5.3	6.0	6.7	7.3	8.0
31	Join	0.6	1.3	1.9	2.6	3.2	3.9	4.5	5.2	5.8	6.5	7.1	7.8
32	Set/Close Collar	1.3	2.7	4.0	5.4	6.7	8.1	9.4	10.8	12.1	13.4	14.8	16.1
33	Mark Buttondown Buttons	0.3	0.7	1.0	1.3	1.7	2.0	2.4	2.7	3.0	3.4	3.7	4.0
34	BHBS Band,BS Buttondown Buttons	0.4	0.9	1.3	1.7	2.2	2.6	3.0	3.5	3.9	4.3	4.8	5.2
35	BS Extra Button on Front	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.1	1.2	1.3
36	1st Sleeve	0.9	1.7	2.6	3.4	4.3	5.1	6.0	6.8	7.7	8.5	9.4	10.2
37	2nd Sleeve	0.9	1.7	2.6	3.4	4.3	5.1	6.0	6.8	7.7	8.5	9.4	10.3
38	T & E after Sleeve	1.2	2.3	3.5	4.7	5.8	7.0	8.1	9.3	10.5	11.6	12.8	14.0
39	1st Fell	1.2	2.5	3.7	5.0	6.2	7.5	8.7	9.9	11.2	12.4	13.7	14.9
40	2nd Fell	1.1	2.1	3.2	4.2	5.3	6.4	7.4	8.5	9.6	10.6	11.7	12.7
41	Set Cuff	1.6	3.1	4.7	6.3	7.8	9.4	11.0	12.6	14.1	15.7	17.3	18.8
42	Hem Bottom	0.7	1.4	2.1	2.9	3.6	4.3	5.0	5.7	6.4	7.1	7.8	8.6
43	Final T & E	1.5	2.9	4.4	5.8	7.3	8.7	10.2	11.6	13.1	14.5	16.0	17.4
44	Collar Press	0.2	0.3	0.5	0.6	0.8	1.0	1.1	1.3	1.4	1.6	1.7	1.9
45	Front Press	0.4	0.7	1.1	1.5	1.8	2.2	2.6	2.9	3.3	3.7	4.1	4.4
46	Fold Long Sleeve	1.6	3.1	4.7	6.3	7.8	9.4	11.0	12.5	14.1	15.7	17.2	18.8
	No. of workstations with 90<=efficiency<=110	5	15	18	26	24	33	33	31	35	35	36	37
	Total theoretical number of operators	24.9	49.9	74.8	99.7	124.7	149.6	174.5	199.5	224.4	249.3	274.3	299.2

Table 5.3: Information used in simulation modeling of mixed MP/MC manufacturing

Operation No	Operation	No of Op. with Qty 3000	Operator x Efficiency	Operator Number	Station Number
1	Auto Make Collar	1.7	2x85%	1,2	1
2	Turn,Press Topstitch Collar	2.7	3x90%	3,4,5	2
3	Trim and Notch Collar	1.3	1x125%	6	3
4	BH Collar Points	1.0	1x100%	7	4
5	Hem Square Band	2.0	2x100%	8,9	5
6	Band Collar	4.6	5x92%	10-14	6
7	Turn,T & E Band	3.3	3x110%	15,16,17	7
8	Beadstitch Band	2.7	3x90%	18,19,20	8
9	Trim Band	1.2	1x120%	21	9
10	Notch Band	0.9	1/90%	22	10
11	Hem Button Front	1.2	1x120%	23	11
12	BS Button Front Auto	0.9	1x90%	24	12
13	Run Topcenter Auto	1.2	1x120%	25	13
14	BH Front Auto	1.3	1x125%	26	14
15	Examine,Trim and Pair Fronts	5.3	5x106%	27-31	15
16	Auto Hem Pocket	0.9	1x90%	32	16
17	Monogramming	1.0	1x100%	33	17
18	Set Pocket-Solid	1.6	2x80%	34,35	18
19	Hem Cuff Auto	1.6	2x80%	36,37	19
20	Make Cuff Auto	2.0	2x100%	38,39	20
21	Turn and Press Cuff	1.7	2x85%	40,41	21
22	Topstitch Cuff	1.8	2x90%	42,43	22
23	BH Cuff	1.5	2x75%	44,45	23
24	BS Cuff	0.9	1x90%	46	24
25	Set Wide Sleeve Facing	3.0	3x100%	47,48,49	25
26	Set Narrow Sleeve Facing	2.7	3x90%	50,51,52	26
27	Block Sleeve Facing	5.4	5x108%	53-57	27
28	T & E Sleeve	2.7	3x90%	58,59,60	28
29	Sew Label to Yoke	4.1	4x102.5%	61-64	29
30	Bartack Yoke for Pleat	1.2	1x120%	65	30
31	Manual Yoke w/Center Pleat	4.0	4x100%	66-69	31
32	Join	3.9	4x97.55	70-73	32
33	Set/Close Collar	8.1	8x101.25%	74-81	33
34	Mark Buttondown Buttons	2.0	2x100%	82,83	34
35	BHBS Band,BS Buttondown Buttons	2.6	3x87%	84,85,86	35
36	BS Extra Button on Front	0.6	1x85%	87	36
37	1st Sleeve	5.1	5x102%	88-92	37
38	2nd Sleeve	5.1	5x102%	93-97	38
39	T & E after Sleeve	7.0	7x100%	98-104	39
40	1st Fell	7.5	7x107%	105-111	40
41	2nd Fell	6.4	6x107%	112-117	41
42	Set Cuff	9.4	9x104%	118-126	42
43	Hem Bottom	4.3	4x107.5%	127-130	43
44	Final T & E	8.7	8x109%	131-138	44
45	Collar Press	1.0	1x100%	139	45
46	Front Press	2.2	2x110%	140,141	46
47	Fold Long Sleeve	9.4	9x104%	142-150	47
	Total	150.6			

5.2.1.2.2.1 Simulation Tool Calibration and Sensitivity Analysis - PBS

Data from the Excel spreadsheet instrument with the evaluated line balance system was used as the base manufacturing system for simulation. The bundle size of 12 was selected as the base bundle size for the MP Progressive Bundle System manufacturing simulation. The Progressive Bundle System has 47 stations with 150 operators that can produce 3000 shirts per day. After critical analysis and practice with various starting work-in-process configurations, this base simulation model was calibrated to have line operator utilization of 90.44% (% time processing) and line machine utilization of 90.42% (% time processing). The starting work-in-process level of 3 bundles of 12 for MP orders and 2 bundles of 1 for customized orders was maintained for each operation. As per the information obtained from the plant, the operation time for the monogramming operation consists of time allowed for set up delays for changing thread color, etc. thus setup time for this operation was not specifically considered in the simulation model.

The model was analyzed for its sensitivity with the data from the Excel spreadsheet instrument and the data from the simulation output results for the base model. Possible calculated results such as total units ordered, total units completed, production line capacity and line efficiency were matched with the simulation results.

5.2.1.2.2.2 Experimental Design – PBS

The primary expectation was to simulate the mixing of customized apparel product with the MP and to explore the outcome when the customized volume increases. To achieve this goal, the experiment was designed to vary the bundle size and sequencing the MP and MC orders in the same production line. In the mixing process bundle sizes of 6, 12, 18, and 36 were considered. Bundle size 24 was not considered due to the incompatibility in standardizing the system for varying bundle sizes with respect to the starting work-in-process levels. As it was observed that the simulation run for a single day does not provide accurate information with larger bundle sizes, the simulation run could extend up to 4 days given the limitations of $[TC]^2$ TeamMate®. The MP and MC orders were considered as two styles Style1 and Style2.

- Style 1 = Base style for MP orders
- Style 2 = Base Style for MP orders + Customized Operation

The order sequencing can be graphically shown as in the Figure 5.4. As illustrated, the MP operations are carried out in stations 1, 2, 4, and 5 whereas the customized operation is taken place at station 3.

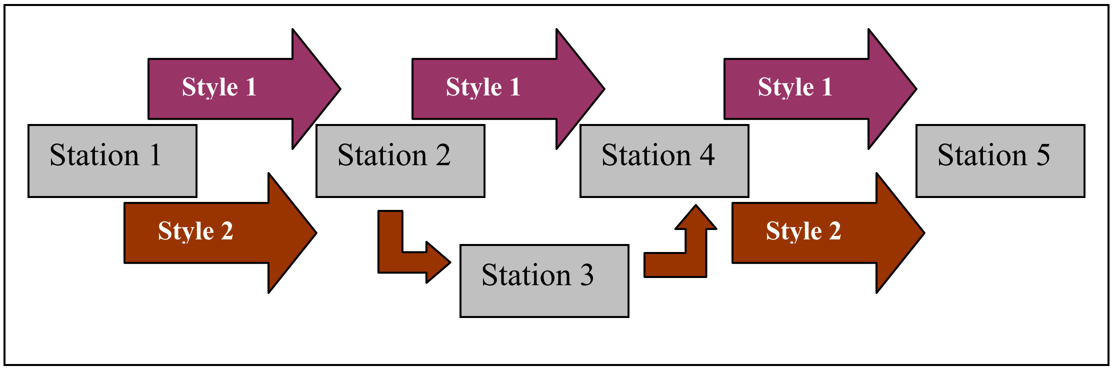

Figure 5.4: MP and MC order sequencing for mixed MP/MC manufacturing simulation

For Mass Production the bundle arrival pattern was set as Style1 - Style 1 - Style 1 and so on where as for MC manufacturing it was Style1 - Style 2 - Style1 - Style2 and so on. This repeat pattern was developed in various scenarios for bundle sizes 6, 12, 18 and 36 as shown in the Table 5.4.

Note: While other simulations often randomize the order arrival or use a distribution function to generate replications, the experimental plan shows predetermined order arrival scenarios. This was necessary to obtain comparative data between bundle size scenarios.

The bundle arrival was planned based on the Periodic Order[1] arrival to make sure that the total order quantity to arrive at the manufacturing line was within the simulation duration i.e. 1-5 days respectively.

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[1] See Appendix B: [TC]^2 TeamMate® Apparel Production Simulation Tool

Table 5.4: Simulation scenario development - PBS

							Order Quantity							
							3000		6000		9000		12000	
							Simulation Run							
							1 day		2 days		3 days		4 days	
Repeat S1/S2	**S1 Lot Size**	**S2 Lot Size when S1=S2**	**S2 Lot Size when S1#S2**	**Units Per Batch of S1**	**Units Per Batch of S2 when S1=S2**	**Units Per Batch of S2 when S1#S2**	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**
6/1	6	1	1	6	1	1	2571	429	5143	857	7714	1286	10286	1714
6/2	6	2	2	6	2	1	2250	750	4500	1500	6750	2250	9000	3000
6/3	6	3	3	6	3	1	2000	1000	4000	2000	6000	3000	8000	4000
6/6	6	6		6	6		3000		6000		9000		12000	
12/1	12	1	1	12	1	1	2769	231	5538	462	8308	692	11077	923
12/2	12	2	2	12	2	1	2571	429	5143	857	7714	1286	10286	1714
12/3	12	3	3	12	3	1	2400	600	4800	1200	7200	1800	9600	2400
12/4	12	4	4	12	4	1	2250	750	4500	1500	6750	2250	9000	3000
12/6	12	6	6	12	6	1	2000	1000	4000	2000	6000	3000	8000	4000
12/12	12	12		12	12		3000		6000		9000		12000	
18/1	18	1	1	18	1	1	2842	158	5684	316	8526	474	11368	632
18/2	18	2	2	18	2	1	2700	300	5400	600	8100	900	10800	1200
18/3	18	3	3	18	3	1	2571	429	5143	857	7714	1286	10286	1714
18/6	18	6	6	18	6	1	2250	750	4500	1500	6750	2250	9000	3000
18/9	18	9	9	18	9	1	2000	1000	4000	2000	6000	3000	8000	4000
18/18	18	18		18	18		3000		6000		9000		12000	
36/1	36	1	1	36	1	1	2919	81	5838	162	8757	243	11676	324
36/2	36	2	2	36	2	1	2842	158	5684	316	8526	474	11368	632
36/3	36	3	3	36	3	1	2769	231	5538	462	8308	692	11077	923
36/6	36	6	6	36	6	1	2571	429	5143	857	7714	1286	10286	1714
36/12	36	12	12	36	12	1	2250	750	4500	1500	6750	2250	9000	3000
36/18	36	18	18	36	18	1	2000	1000	4000	2000	6000	3000	8000	4000
36/36	36	36		36	36		1500	1500	6000		9000		12000	

5.2.1.2.2.3 Scenario Development – PBS

Table 5.4 describes the scenarios that were developed for mixed MP and MC shirt manufacturing. S1 and S2 are the interchanging styles that are repeated which can be MP or MC batches. S1=S2 when all the batches are of Style S1 (MP order) and S1≠S2 when the MP (Style S1) and MC (Style S2) batches are arriving intermittently. The lot size as described in the Table 5.4 is same as the batch size (or bundle size) and units per batch are the number of shirts that come as a single batch to the production line queue. The order quantities for individual days of simulation runs are shown in the last 8 columns. Based on the scenarios for mixed MP, MC manufacturing, the number of operators for the customized operation was adjusted to balance the line for the monogramming operation with the following premise.

For S1/S2 repeat when S1≠S2:

- SAM Ratio = S2*SAM for customized operation / (S1+S2)*total SAM for the shirt
- Number of operators for the customized operation

  = SAM Ratio* Total Number of regular operators

The calculation of the ratios and the number of operators who carry out the customized operation is described in the Table 5.5.

Table 5.5: Balancing the line for customized operation with changing Batch Size

Repeat S1/S2	S1 Lot Size	S2 Lot Size when S1#S2	Ratio (Premise)	Theoritical No of Monogramming Operators	No of Monogramming Operators	Efficiency %
6/1	6	1	0.023873	3.56	3	119
6/2	6	2	0.041778	6.22	6	104
6/3	6	3	0.055704	8.30	8	104
6/6	6					
12/1	12	1	0.012855	1.92	2	96
12/2	12	2	0.023873	3.56	3	119
12/3	12	3	0.033423	4.98	5	100
12/4	12	4	0.041778	6.22	6	104
12/6	12	6	0.055704	8.30	8	104
12/12	12					
18/1	18	1	0.008795	1.31	1	131
18/2	18	2	0.016711	2.49	2	124
18/3	18	3	0.023873	3.56	3	119
18/6	18	6	0.041778	6.22	6	104
18/9	18	9	0.055704	8.30	8	104
18/18	18					
36/1	36	1	0.004517	0.67	1	85
36/2	36	2	0.008795	1.31	1	131
36/3	36	3	0.012855	1.92	2	96
36/6	36	6	0.023873	3.56	3	119
36/12	36	12	0.041778	6.22	6	104
36/18	36	18	0.055704	8.30	8	104
36/36	36					

5.2.1.2.2.4 Operational Assumptions for Simulation – PBS

1. The conclusions were based on primarily balancing the line for a bundle size of 12 for one day at an average efficiency of 90%. Concurrent manufacturing of sub-assembly and final assembly system was considered.

2. The operator efficiency range can be 85-125% other than the customizing operation which can be up to 131%.
3. More than one day of production was selected to see the perturbation as the results were shown accurate as for bigger bundle sizes (such as 36) compared to the single day production run.
4. Even though the expectation in mixed MP, MC manufacturing was to queue custom orders randomly, the system was set up to process the custom batches alternating with MP batches. Evaluating this extreme level provided the flexibility to research a less frequent extent of customized batch arrival.
4. Only one Feature Customization operation was considered to reduce the complexity of matching simulation requirement with the $[TC]^2$ TeamMate® model.
5. The order and batch arrival pattern was defined using the "periodic order" system with time between arrivals as 1.1 minutes.
6. The starting WIP level of 36 garment parts or garments was considered with respective bundle size adjustments for all the scenarios.

5.2.1.2.3 Strategy 2: Integrating MP Product into MC Manufacturing System: Kanban Production Line

Due to the system constraints of the simulation tool, an exact UPS system could not be simulated. This is because the tool does not have the functionality to re-route the parts through workstations as it could be done with the UPS. Therefore, using the Kanban workstations a Kanban Production System was simulated to integrate MP product into

MC manufacturing system. This is a production line with sequential operations where material flow is controlled by Kanbans at each workstation. The operators could move between workstations based on the developed movement rules as modeled base on the line balance.

The operation breakdown for the MC shirt style is shown in Table 5-6. Due to confidentiality the SAM values are not disclosed. As it was required to identify a good line balance with good line efficiency, the number of operators required and their efficiencies for a production quantity of 300 per day was analyzed using an Excel spreadsheet model as shown in the Table 5-7. The production quantity of 300 is the capacity for MC production practiced by the company.

Columns of the Table 5.7 illustrate the theoretical number of operators for each operation/station, the operator efficiencies, operator number, station number and the line balance that were used to model the MC Kanban production line. The arrows in the Line Layout/Operator Balance column show the operator movement between workstations. Number of line balancing scenarios with operator movement rules were used in optimizing the model to obtain the optimum line performance. The color-coded cells also describe the operator sharing machines and stations. Operator efficiency ranges from 80% to 112%. The monogramming operation was considered as the customized operation and the rest of the operations are common for both MC and MP manufacturing.

Table 5.6: MC operation sequence for men's long sleeve pinpoint button down collar, single pocket, barrel cuff shirt.

Op No	Operation
1	Load
2	Make Collar
3	Turn and Press Collar,BH Collar Points
4	Band Collar, T & E, Trim,Hem Band
5	Beadstitch Band, Sew Frt. Label
6	Top Center and Hem Under
7	Bh, Bs Front
8	Trim and Examine
9	Hem pocket - manual straight
10	Set Pocket
11	Monogramming
12	Hem Cuff
13	Make Cuff
14	Turn and Topst.,BSBH Cuff
15	Set Sleeve Facings
16	Block Sleeve Facings, Pleat Sleeve
17	BH,BS Cuff & Placket
18	Set Yoke, Sew Label
19	Join
20	Set and Close Collar
21	First Sleeve,BSBH Band
22	Second Sleeve, T & E Sleeve
23	First Fell,BS Buttondown (mark BD+ Extra button on front)
24	Second Fell
25	Set Cuff
26	Hem Tail
27	T & E 2 BD?
28	Wide Press
29	Fold

Table 5.7: Information used in simulation modeling of mixed MC/MP manufacturing-Kanban Production Line

Operation No	Operation	No. of Ops. with Qty 300	No. of Ops. x Efficiency	Operator Number	Station Number	Line Layout/Operator Balance
1	Load	0.25	1 x 70%	1	1	
2	Make Collar	0.42			2	
3	Turn and Press Collar,BH Collar Points	1.10	1 x 100%	2	3	
4	Band Collar, T & E, Trim,Hem Band	1.12	1 x 100%	3	4	
5	Beadstitch Band, Sew Frt. Label	0.79	1 x 90%	4	5	
6	Top Center and Hem Under	0.97	1 x 97%	5	6	
7	Bh, Bs Front	0.64	1 x 80%	6	7	
8	Trim and Examine	0.88	1 x 88%	7	8	
9	Hem pocket - manual straight	0.22			9	
10	Set Pocket	0.44			10	
11	Monogramming	2.50	3 x 85%	8,9,10	11	
12	Hem Cuff	0.44			12	
13	Make Cuff	0.62	1 x 106%	11	13	
14	Turn and Topst.,BSBH Cuff	0.65	1 x 109%	12	14	
15	Set Sleeve Facings	0.84	1 x 106%	13	15	
16	Block Sleeve Facings, Pleat Sleeve	1.02	1 x 102%	14	16	
17	BH,BS Cuff & Placket	0.59	1 x 112%	15	17	
18	Set Yoke, Sew Label	1.12	1 x 112%	16	18	
19	Join	0.53			19	
20	Set and Close Collar	0.90	1 x 90%	17	20	
21	First Sleeve,BSBH Band	0.95	1 x 95%	18	21	
22	Second Sleeve, T & E Sleeve	0.81	1 x 103%	19	22	
23	First Fell,BS Buttondown (mark BD+ Extra button on front)	1.11	1 x 111%	20	23	
24	Second Fell	0.67	1 x 106%	21	24	
25	Set Cuff	1.01	1 x 101%	22	25	
26	Hem Tail	0.58	1 x 99%	23	26	
27	T & E 2 BD?	1.45	1 x 106%	24	27	
28	Wide Press	2.39	2 x 99	25,26	28	
29	Fold	1.24	1 x 103%	27	29	
	Total	26.24		27	29	No of Machines = 35

5.2.1.2.3.1 Simulation Tool Calibration and Sensitivity Analysis – Kanban Production Line

Data from the Excel spreadsheet model with the evaluated line balance system was used as the base manufacturing system for Kanban line simulation. The Kanban station WIP limits were selected based on the premise that at a given time the line consists of 300 shirts. The purpose is to retain the TPT at less than one day for the mass-customized shirts. The simulation duration was for a single day. The line consists of 27 operators working at 29 stations that utilize 35 machines to produce 300 shirts per day. After critical analysis and practice with various starting work in process configurations, this base simulation model was calibrated to have line operator utilization of 79.63% (% time processing) with a starting station WIP of 6 garments. As the original intention was to simulate a UPS, the Kanban line was set to have a garment bundle unit of one moving in the line.

The model was analyzed for its sensitivity with the data from the Excel spreadsheet model and the data from the simulation output results for the base model. Possible calculated results such as total units ordered, total units completed, production line capacity and line efficiency were matched with the simulation results.

5.2.1.2.3.2 Experimental Design – Kanban Production Line

The primary expectation was to simulate the mixing of MP apparel products with MC and to explore the outcome when the MP volume increases. To achieve this goal, the experiment was designed to allow arrival of varying bundle sizes of MP to the Kanban line at intervals that simulates the random MC/MP mixed manufacturing. After arrival the bundle seperates into single parts/garments and will move in the line as single units. In the mixing process bundle sizes of 6, 12, 18, and 36 were considered in order to follow the same setup as the PBS simulation. The simulation was set to run for a single day. The MC and MP orders were considered as two styles, Style1 and Style2 respectively.

- Style 1 = Base style for MC orders
- Style 2 = Base Style for MC orders without the customization operation

The order sequencing can be graphically shown as in the Figure 5.5. As illustrated the MC orders are sequenced through stations 1, 2, 3, 4, and 5 whereas the MP orders skip station 3 (station with customized operation).

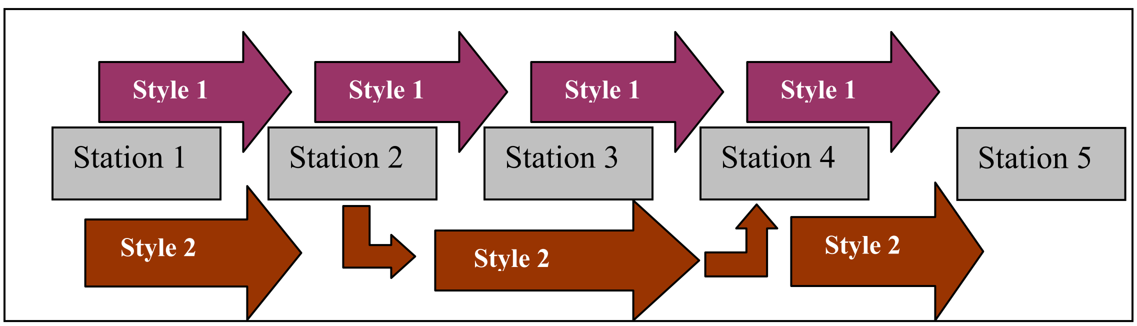

Figure 5.5: MC and MP order sequencing for mixed MC/MP manufacturing simulation

For MC only, the order arrival pattern was set as Style1 - Style 1 - Style 1 and so on whereas for MC/MP mixed manufacturing it was Style1 - Style 2 - Style1 - Style2 and so on. This repeat pattern was developed with number of scenarios for bundle sizes 6, 12, 18 and 36 as shown in the Table 5.8.

Note: While other simulations often randomize the order arrival or use a distribution function to generate replications, the experimental plan shows predetermined order arrival scenarios. This was necessary to obtain comparative data between bundle size scenarios.

Both MC and MP order arrival were planned based on the Periodic Order[1] arrival to make sure that the total order quantity to arrive at the manufacturing line was within the simulation duration, i.e. one day.

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[1] See Appendix B: [TC]^2 TeamMate® Apparel Production Simulation Tool

Table 5.8: Simulation scenario development – Kanban Production Line

Repeat S1/S2	S1 Lot Size	S2 Lot Size when S1=S2	S2 Lot Size when S1#S2	Units Per Batch of S1	Units Per Batch of S2 when S1=S2	Units Per Batch of S2 when S1#S2	Order Quantity S1	Order Quantity S2	Theoretical No. of Monogramming Operators when S1#S1
1/6	1	6	6	1	1	1	43	257	0.36
2/6	2	6	6	1	1	1	75	225	0.63
3/6	3	6	6	1	1	1	100	200	0.83
1/12	1	12	12	1	1	1	23	277	0.19
2/12	2	12	12	1	1	1	43	257	0.36
3/12	3	12	12	1	1	1	60	240	0.50
4/12	4	12	12	1	1	1	75	225	0.63
6/12	6	12	12	1	1	1	100	200	0.83
1/18	1	18	18	1	1	1	16	284	0.13
2/18	2	18	18	1	1	1	30	270	0.25
3/18	3	18	18	1	1	1	43	257	0.36
6/18	6	18	18	1	1	1	75	225	0.63
9/18	9	18	18	1	1	1	100	200	0.83
1/36	1	36	36	1	1	1	8	292	0.07
2/36	2	36	36	1	1	1	16	284	0.13
3/36	3	36	36	1	1	1	23	277	0.19
6/36	6	36	36	1	1	1	43	257	0.36
12/36	12	36	36	1	1	1	75	225	0.63
18/36	18	36	36	1	1	1	100	200	0.83

5.2.1.2.3.3 Scenario Development - Kanban Production Line

Table 5.8 describes the scenarios that were developed for mixed MC and MP shirt manufacturing. S1 and S2 are the interchanging styles that are repeated which represent MC and MP batches. S1=S2 when all the batches are of Style S1 (MC order) and S1≠S2 when the MC (Style S1) and MP (Style S2) batches arrive intermittently. The lot size as described in the Table 5.8 is the same as the batch size, and units per batch are the number of shirts that come as a single batch to the production line queue. The order quantities for a single day of simulation runs are shown. Based on the scenarios for mixed MC/MP manufacturing, the theoretical number of operators for the customized operation were calculated (when S1#S2) and shown in the last column. A single monogramming operator was sufficient for the line when the orders are mixed. An operator of 85% efficiency was assigned to the line when S1≠S2.

5.2.1.2.3.4 Operational Assumptions for Simulation – Kanban Production Line

1. As the simulation tool was not able to model a UPS line, a Kanban line was simulated to explore the MC/MP mixed manufacturing.
2. The conclusions were based on primarily balancing the line that manufactures 300 mass-customized shirts per day. A line performance of 80% was obtained for a one-time order of 300 mass-customized shirts.
3. The monogramming operator efficiency was assigned at 85% when MC and MP orders were simulated even though the required efficiencies were varied.

4. Even though the expectation of mixed manufacturing was to queue MC and MP orders randomly, the system was set up to process the MC batches alternating with MP batches. Evaluating this extreme level provided the flexibility to research a less frequent extent of MP batch arrival.

5. Only one Feature Customization operation was considered to reduce the complexity of matching simulation requirement with the $[TC]^2$ TeamMate® model.

6. The order and batch arrival pattern was defined using the “periodic order” function with time between arrivals as 1.1 minutes.

7. The starting WIP level of 6 garment parts or garments was considered.

8. For the Kanban line, the operation breakdown, standard times, the distances between workstations and material movement speeds were simulated with information from a Unit Production System.

As the modeled MC Kanban line’s behavior had considerable amount of unexplained variations, it was decided to use the same line as a MP line and introduce MC units to explore the mixed manufacturing performance.

5.2.1.2.4 Strategy 1: Integrating MC Product into MP Manufacturing System: Kanban Production Line.

The Kanban Production System that was modeled to investigate the Strategy 2, was used in this simulation. The operation sequence as shown in the Table 5.6 was used with Monogramming as the Feature Customization. The line balance as illustrated in the

Table 5.7 was used except station 11, where instead of 3 operators, only 1 operator was required. The adjusted information is shown in Table 5.9.

Table 5.9: Information used in simulation modeling of mixed MP/MC manufacturing – Kanban Production Line

Operation No	Operation	No. of Ops. with Qty 300	No. of Ops. x Efficiency	Operator Number	Station Number	Line Layout/Operator Balance
1	Load	0.25	1 x 70%	1	1	
2	Make Collar	0.42			2	
3	Turn and Press Collar,BH Collar Points	1.10	1 x 100%	2	3	
4	Band Collar, T & E, Trim,Hem Band	1.12	1 x 100%	3	4	
5	Beadstitch Band, Sew Frt. Label	0.79	1 x 90%	4	5	
6	Top Center and Hem Under	0.97	1 x 97%	5	6	
7	Bh, Bs Front	0.64	1 x 80%	6	7	
8	Trim and Examine	0.88	1 x 88%	7	8	
9	Hem pocket - manual straight	0.22			9	
10	Set Pocket	0.44			10	
11	Monogramming	1.00	1 x 85%	8	11	
12	Hem Cuff	0.44			12	
13	Make Cuff	0.62	1 x 106%	9	13	
14	Turn and Topst.,BSBH Cuff	0.65	1 x 109%	10	14	
15	Set Sleeve Facings	0.84	1 x 106%	11	15	
16	Block Sleeve Facings, Pleat Sleeve	1.02	1 x 102%	12	16	
17	BH,BS Cuff & Placket	0.59	1 x 112%	13	17	
18	Set Yoke, Sew Label	1.12	1 x 112%	14	18	
19	Join	0.53			19	
20	Set and Close Collar	0.90	1 x 90%	15	20	
21	First Sleeve,BSBH Band	0.95	1 x 95%	16	21	
22	Second Sleeve, T & E Sleeve	0.81	1 x 103%	17	22	
23	First Fell,BS Buttondown (mark BD+ Extra button on front)	1.11	1 x 111%	18	23	
24	Second Fell	0.67	1 x 106%	19	24	
25	Set Cuff	1.01	1 x 101%	20	25	
26	Hem Tail	0.58	1 x 99%	21	26	
27	T & E 2 BD?	1.45	1 x 106%	22	27	
28	Wide Press	2.39	2 x 99	23,24	28	
29	Fold	1.24	1 x 103%	25	29	
	Total	24.74		25	29	No of Machines = 33

5.2.1.2.4.1 Simulation Tool Calibration and Sensitivity Analysis - Kanban Production Line

Data from the Excel spreadsheet model with the adjusted line balance system was used as the base manufacturing system for Kanban MP line simulation. The same Kanban station WIP limits were selected as discussed before to remain the TPT less than one day for the mass-customized shirts. The simulation duration was for a single day. The line consisted of 25 operators working at 29 stations that utilized 33 machines to produce 300 shirts per day. With the same work in process levels used before, this base simulation model was calibrated to have line performance of 82.95%. As the original intention was to simulate a UPS, the Kanban line was set to have a garment unit of one moving in the line.

The model was analyzed for its sensitivity with the data from the Excel spreadsheet instrument and the data from the simulation output results for the base model. Possible calculated results such as total units ordered, total units completed, production line capacity and line efficiency were matched with the simulation results.

5.2.1.2.4.2 Experimental Design – Kanban Production Line

The research objective of this simulation was to investigate the line behavior when the MP orders were mixed with increasing MC volumes. To achieve this goal, the experiment was designed to allow arrival of varying lot sizes of MC to the Kanban line at intervals that simulate the random MP/MC mixed manufacturing. After the arrival, the MP bundle separates into single parts/garments and will move through line as a unit of one. In the mixing process bundle sizes of 6, 12, 18, and 36 were considered in order to follow the same sequence as the previous experiment. The simulation was set to run for a single day. The MC and MP orders were considered as two styles, Style1 and Style2 respectively.

- Style 1 = Base style for MP orders
- Style 2 = Base Style for MP orders + Customized Operation

The order sequencing can be graphically shown as in the Figure 5.6. As illustrated, the MC orders are sequenced through stations 1, 2, 3, 4, and 5 whereas the MP orders skip station 3, which is the station with customized operation.

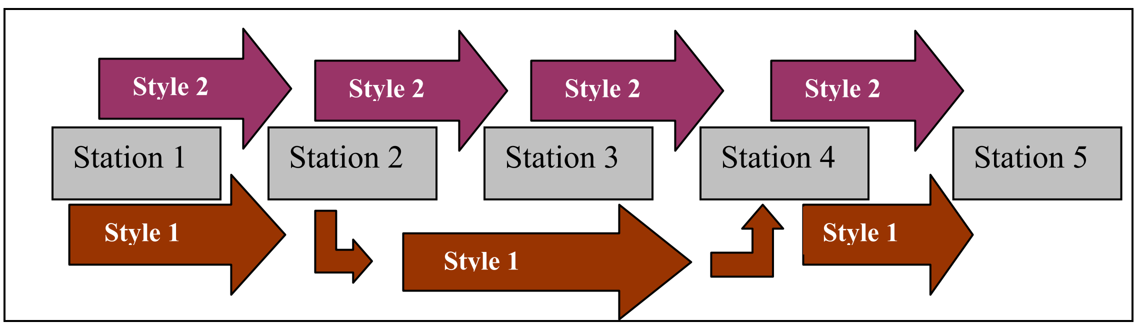

Figure 5.6: MP and MC order sequencing for mixed MP/MC manufacturing simulation

For MP only, the order arrival pattern was set as Style1 - Style 1 - Style 1 and so on where as for MP/MC mixed manufacturing it was Style1 - Style 2 - Style1 - Style2 and so on. This repeat pattern was developed with number of scenarios for bundle sizes 6, 12, 18 and 36 as shown in the Table 5.10.

Note: While other simulations often randomize the order arrival or use a distribution function to generate replications, the experimental plan shows predetermined order arrival scenarios. This was necessary to obtain comparative data between bundle size scenarios.

The MP and MC order arrival was planned based on the Periodic Order[1] arrival to make sure that the total order quantity to arrive at the manufacturing line was within the simulation duration, i.e. one day.

Table 5.10: Simulation scenario development – Kanban Production Line

Repeat S1/S2	S1 Lot Size	S2 Lot Size when S1=S2	S2 Lot Size when S1#S2	Units Per Batch of S1	Units Per Batch of S2 when S1=S2	Units Per Batch of S2 when S1#S2	Order Quantity S1	Order Quantity S2
6/1	6	1	1	1	1	1	43	257
6/2	6	2	2	1	1	1	75	225
6/3	6	3	3	1	1	1	100	200
12/1	12	1	1	1	1	1	23	277
12/2	12	2	2	1	1	1	43	257
12/3	12	3	3	1	1	1	60	240
12/4	12	4	4	1	1	1	75	225
12/6	12	6	6	1	1	1	100	200
18/1	18	1	1	1	1	1	16	284
18/2	18	2	2	1	1	1	30	270
18/3	18	3	3	1	1	1	43	257
18/6	18	6	6	1	1	1	75	225
18/9	18	9	9	1	1	1	100	200
36/1	36	1	1	1	1	1	8	292
36/2	36	2	2	1	1	1	16	284
36/3	36	3	3	1	1	1	23	277
36/6	36	6	6	1	1	1	43	257
36/12	36	12	12	1	1	1	75	225
36/18	36	18	18	1	1	1	100	200

[1] See Appendix B: [TC]^2 TeamMate® Apparel Production Simulation Tool

5.2.1.2.4.3 Scenario Development – Kanban Production Line

Table 5.10 describes the scenarios that were developed for mixed MP and MC shirt manufacturing. S1 and S2 are the interchanging styles that are repeated which represent MP and MC batches. S1=S2 when all the batches are of Style S1 (MP order) and S1≠S2 when the MP (Style S1) and MC (Style S2) batches arrive intermittently. The lot size as described in the Table 5.10 is the same as the batch size and units per batch are the number of shirts that come as a single batch to the production line queue. The order quantities for single day of simulation run are shown.

5.2.1.2.4.4 Operational Assumptions for Simulation – Kanban Production Line

1. For the Kanban line, the operation breakdown, standard times, the distances between workstations and material movement speeds were simulated with information from a Unit Production System.
2. The conclusions were based on primarily balancing the line that manufactures 300 MP shirts per day. A line performance of 83% was obtained for a one-time order of 300 MP shirts.
3. One operator was assigned for the monogramming operation with an efficiency of 85%.
4. Even though the expectation of mixed manufacturing was to queue MP and MC orders randomly, the system was set up to process the MP batches alternating with MC batches. Evaluating this extreme level provided the flexibility to research a less frequent extent of MC batch arrival.

5. Only one Feature Customization operation was considered to reduce the complexity of matching simulation requirement with the $[TC]^2$ TeamMate® model.
6. The order and batch arrival pattern was defined using the “periodic order” function with time between arrivals as 1.1 minutes.
7. The starting WIP level of 6 garment parts or garments was considered.

5.2.2 Apparel Industry Survey on Mixed MP and MC Apparel Manufacturing

5.2.2.1 Survey Instrument Development

The research suggested exploring the industry practice of customized apparel manufacturing particularly to meet the objectives that were developed in Chapter 4. The research objective for the survey was to identify the current MC practices in the apparel industry to benchmark the customized apparel manufacturing in relation to the following.

- Apparel categories that are customized
- Customization extent based on the author developed “Points of Customization” – These terminologies were defined at each customization point and questions were designed to capture the industry practice based on information collected from extensive research.
- Customization leadtime as a benchmarking parameter
- Mixed or independent MP and MC practice – Manufacturing section of the survey instrument was divided into three sections which collect information on mixed MP and MC practice, i.e. the manufacturing is taking place in the same

production line or assembled in separate production lines. Each of these sections was color-coded and instructions were available for routing to other knowledgeable persons in the company.

- Systems, technology and techniques and the leadtimes for mass-customized apparel manufacturing – Pattern making, marker making, cutting and assembly systems and techniques, and cutting technologies were surveyed. In addition, leadtime information for these was researched.
- Country or place of manufacturing and the leadtimes
- Mixed or independent MP and MC apparel distribution business practices
- MP and MC cost comparison
- Additional questions - Company and user profile, inquiring the willingness to further assist in case studies, and other recommendations of MC practiced companies and their contact information were surveyed.

The survey instrument was designed (Appendix C1) and developed using the knowledge gathered through the literature review, case study, and experience gathered through simulating the mixed apparel manufacturing. As Dillman (2000) discusses, to obtain a good response rate, the participating individuals were offered with the easiest way of responding to the questions asked (Dillman, 2000). Therefore, most of the questions were designed as direct questions to provide a selection from the available answers. To make the response route more flexible, the sections were color coded so that the instrument could be transferred to individual departments within or among the same organization. Other than the cover letter, a brief description of the survey, purpose, importance, acknowledgement, contact information in case of questions, and author's intended feedback of analyzed results were added to the face page of the survey instrument. Data collection strategy discussed by Dillman (2000) was used to design a cover letter (Appendix C2) which was personalized and directed to the individual official in the organization. This personalization approach was selected to overcome the problem of poor responses that the surveys are subjected to with the overflowing numbers of surveys carried out by many individuals and organization for academic and non-academic purposes. Also, the medium was selected as “Mail Survey” to be able to personalize the survey.

5.2.2.2 Data Collection

A list of the possible companies and their addresses, a tentative contact person, his/her telephone contact information and a column for follow up details were tabulated as shown in the Table 5.11.

Table 5.11 Contact information and survey follow-up “Template”

Company Name	Address	Contact Person/s	Contact Information	Mailing Date	Follow-up: Date/Feed Back/Next Contact
Company A					
Company B					

Each individual was contacted and the information was updated with contact information of an appropriate official from the company who has the authority and knowledge to respond to the survey. The instrument was then sent by mail with the cover letter, a self-addressed stamped envelope and a token of appreciation (NC State, College of Textiles book mark). After two weeks from the first mailing date of each survey a follow up telephone contact sessions were made. Survey was re-sent by means of mail or fax to few companies that have either not received it or needed it to be sent to another person or location. Based on the requirement, a follow up telephone contact sessions were made regularly until the responses were received. None of the companies declined to participate in the survey but some requested additional information for clarification and more time to respond. The final sample size of 16 responses out of the population size of 24 (n=24) was obtained. This response rate of 67% is very much higher than the average response rate (21%) of the industry surveys (Dillman, 2000). A "thank you" letter (Appendix C3) was sent after the initial 67% responses to all 24 target participants, encouraging the non-respondents to respond, promising that the analyzed results from the survey will be sent after preparing the dissertation.

5.2.2.3 Data Analysis

The qualitative and quantitative information was transferred to Excel worksheets having each section of the survey being transcribed in to a single worksheet. First the individual sections were separately analyzed and then they were examined to identify relationship with other sections. To achieve this goal the separate worksheets were merged into one worksheet which was coded to sort as intended so that planned ways of data analysis was accomplished.

5.2.3 Case Study on Mixed MP and MC Apparel Practices

5.2.3.1 Case study design

A Case Study was conducted with the firm that also assisted in providing information for the simulation method. This company has the expertise in manufacturing for both MP and MC. The Case Study instrument was developed as shown in Appendix D. This Case Study was conducted in person in the manufacturing plant. The instrument was developed to understand the practice of apparel mass-customization, extending from customer design input to delivery of customized apparel products.

The Case Study method was designed based on the book "Case Study Research: Design and Methods" (Yin, 2003). The "case study questions" were modeled to gather information in the areas of order management, pre-production, production (cutting), preparation for sewing, production (sewing), finishing and packing, shipping, general and financial aspect of apparel MC. The "proposition" of the Case Study was to understand in depth the current practice of mass-customized apparel manufacturing and to explore the opportunities of a mixed MP and MC apparel manufacturing strategy. The "unit of analysis" for the case study was the manufacturing process for an apparel product.

5.2.3.2 Data Collection

The company was contacted via E-Mail after obtaining their willingness to participate in the case study. Formal interviews were conducted with the company executive who held the responsibilities as General Manager for Manufacturing. A plant visit was made and information from interviewing and observations were recorded under each sectional question.

5.2.3.3 Data Analysis

Data analysis was completed in two stages. The information gathered was first transcribed into paragraph form. Then the Case Study was developed under the primary sections discussed in the “survey instrument development”.

5.2.4 Personal Communication on Mixed MP and MC Apparel Practices

5.2.4.1 Interview Instrument Design

The main expectation in interviewing industry consultants who are familiar with the concept of MC was to seek information regarding current practice and predictions for the future of mass-customized apparel manufacturing. The interviews were also aimed at identifying the companies who practice mixed MP/MC apparel manufacturing, and to explore their perspectives in mixed MP/MC manufacturing. The information and experience obtained from the Case Study and simulation methods assisted in developing the interview instrument (Appendix E). Questions were developed for the instrument targeting information in the areas of understanding MC, mass-customized apparel manufacturing, mixed MP and MC apparel manufacturing, extent of apparel customization, technology available for the industry readiness in apparel MC, cost benefits and the expected future of apparel MC. Three interviews were conducted in person and the fourth via telephone. In general each interview required two hours approximately to complete the Case Study.

5.2.4.2 Data Collection and Analysis

Information from interviews was recorded under each sectional question. A tape recorder was used with the interviewee's permission to capture the information as appropriate. As used in case study approach the data analysis was completed in two stages. The information gathered was first transcribed into paragraph form. Then the information was presented taking the sectional headings into consideration as illustrated in the interview instrument.

CHAPTER 6

6 RESEARCH FINDINGS, RESULTS AND DISCUSSION

6.1 FINDINGS FROM LITERATURE

6.1.1 Manufacturing Attribute Comparison Table

Based on the critical literature review, the following comprehensive apparel manufacturing attribute table was developed which was used in modeling the manufacturing systems for computer simulation. The references used to develop this Table 6.1 are shown below.

Table 6.1: Comprehensive apparel manufacturing attribute table

	Straight Line	**Straight Bundle**	**PBU**	**PBU Skill Center**	**Transporter Systems. (Similar to Straight Bundle)**	**UPS Without/ With Teams**	**Modular**
Team size	40-100	40-100) (Managed inventory lines MIL)				20-40 15-20 UPS teams	4-15 or 8-15 or 7-15
Production unit –Batch Size- (link to WIP inventory)	Single Garment 1	Bundle Group of garments 30-50 30-50 MIL	Bundle 30-50		Bundle	Single garment or few garments 1-3 1-3 UPS Teams	Single garment or a small bundle 1 3-12 6-12 Sit down
WIP	Low	High	High 10 –12 Units between operations	High	High	Lower	Very Low
Service level	Low	Low	Low		Low	High	High
Product Flexibility	Inflexible 1 (weakest)	Inflexible	Better 2	5 (strongest)	Inflexible	Better 3	High 4

Table 6.1 (continued)

Through-Put time, Lead time (e.g. 20min labor content) Lead time Lead Time	Similar to labor content 5 (Strongest)	High (15-20days) 3-5 days MIL 3-5 days	Fairly high/vary, (4-5 or 15-20) 2 7-10 days	1 (Weakest)	Similar to Straight Bundle	Hours 4 <1 day <1 day UPS teams	Hours or labor content 4 <4 hours 1-2 Days
Vulnerable to Absenteeism	1 (Weakest)		4	5 (Strongest)		2	2
Quality Control/Quality	5 (Strongest)		1 (Weakest)	1		4	5
Space Utilization	5 (Strongest) Low		1 High (10 Sq. Met/Op)	1 (Weakest)		3 Less	5
Handling & clerical time for production unit	Low 5 (Strongest)	High	High 1 (Weakest)	1	Little less as manual handling between operations eliminated	Very much less 5	Very Low 4
Employee Involvement	Low	Low	Low		Low	High in teams	Very High
Employee Empowerment, Decision-Making Authority	Low 4	Low	Low 1 (Weakest)	1	Low	High in teams 4	Very High 5 (Strongest)
Direct Labor Requirement, Labor/Machine Ratio	High	High	Comparatively low 1 to 1.5	Further low	High	Can be low	¼ Toyota sewing system
Indirect Labor Requirement	4		1 (Weakest)	1		4 -10%	5 (Strongest) -20%
Individual Productivity	Affect the line 1 (Weakest)	Good	Better Specialization 5 (Strongest)	4	Affects the line	Affects the line 4	2
Skills/Operator	1.5		1.1			1.1	3.5 4
Motivation, Payment System	Same rate for all	Based on performance	Incentive vary with operation		May be line rate		Group

Table 6.1 (continued)

Machine Utilization		80%	85%			85%	40%
SAH/Unit						-3%	+8%
Total cost/unit		+2%					+7%
Capacity Elasticity		2	1 (Weakest)			1	5 (Strongest)
Diversity Recovery*		10 weeks	12 weeks			12 weeks	9 weeks
Implementation Conversion: Maturity:		 3 months 6 months				 3 months 6 months	 8 months 24months
Stand/Sit	Sit	Sit	Sit			Sit	Stand
Sq. Ft./ Work Place		100	110			90	50
Shop Floor Control IT Manual: Computerized Batch: Computerized Real Time:	 Yes Yes Yes	 Slow Slow Slow	 Next day Intermittent Enhanced	 Similar to PBU	 Slow Lack of QR Enhanced	 System geared for real time	 Slow Slow Need for continues reporting

*Recovering the pace with diversity in terms of styles and small quantities.

The above table was compiled with additional data from the following sources:

- Report of the Technical Advisory Committee, AAMA. (1988). (Rating: 1=weakest, 5=strongest)
- Report of the Management Systems Committee, AAMA. (1990).
- Flexible Consumer Response by J. Armfield (1994), Apparel Industry Magazine.
- Making Teams Work by E. Hill. (1995), Bobbin
- Apparel manufacturing sewn product analysis by Glock & Kunz (2000).
- Fashion your future by B. Johnson-Hill (1978).
- Apparel manufacturing strategies, AAMA. (1984).

(It is evident that there are differences between authors information with respect to some parameters, e.g. space utilization, which can be due to some differences of system definitions that have not been clearly specified.)

6.1.2 Web Based MC Business Model

Many of the online businesses which produce customized products related to apparel carryout a similar process even though there is lack of transparency of the manufacturing models. The author developed the general operation procedure or simplified functional model of the business of these online companies as shown in the Figure 6.1, using information from companies who practice mass-customized apparel manufacturing. As this is merely a draft conceptual model, detailed information about the existing business practices is researched with the survey and case study instrument as well as personal communication with the industry experts as discussed later in this chapter.

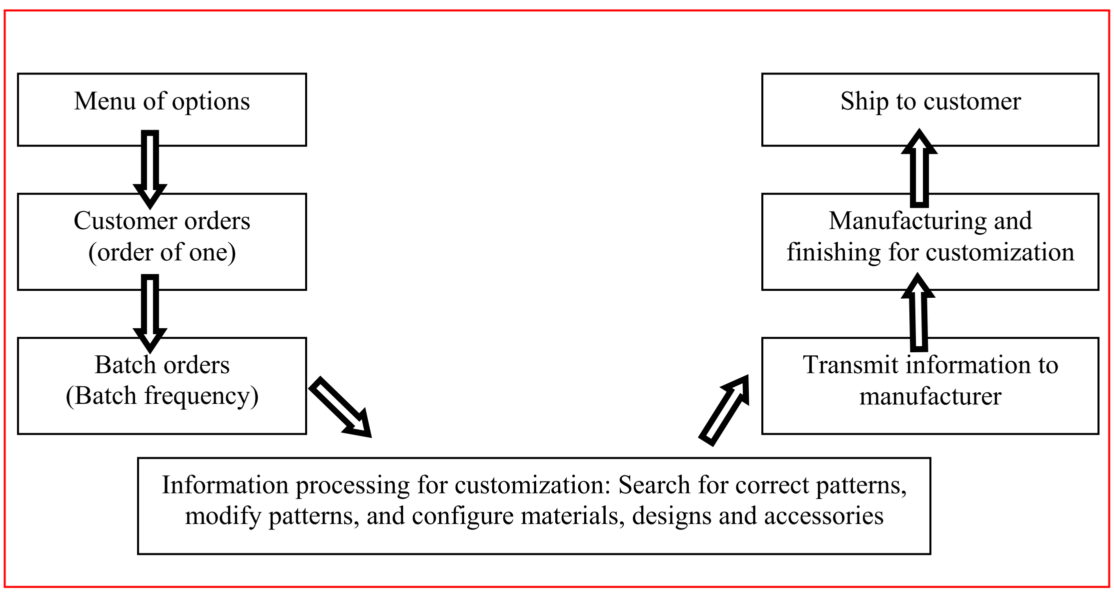

Figure 6.1: Generic functional model for E-commerce based apparel MC

6.1.3 Manufacturing Systems and Technology Infrastructure Model for Mixed MP/MC Practice

Based on the literature review, the author developed the model as shown in Figure 6.2 that addresses the requirements to use the existing manufacturing systems and the technology infrastructure to develop a mixed MP/MC apparel manufacturing system. The individual elements in this model were discussed in detail in Chapter 2.

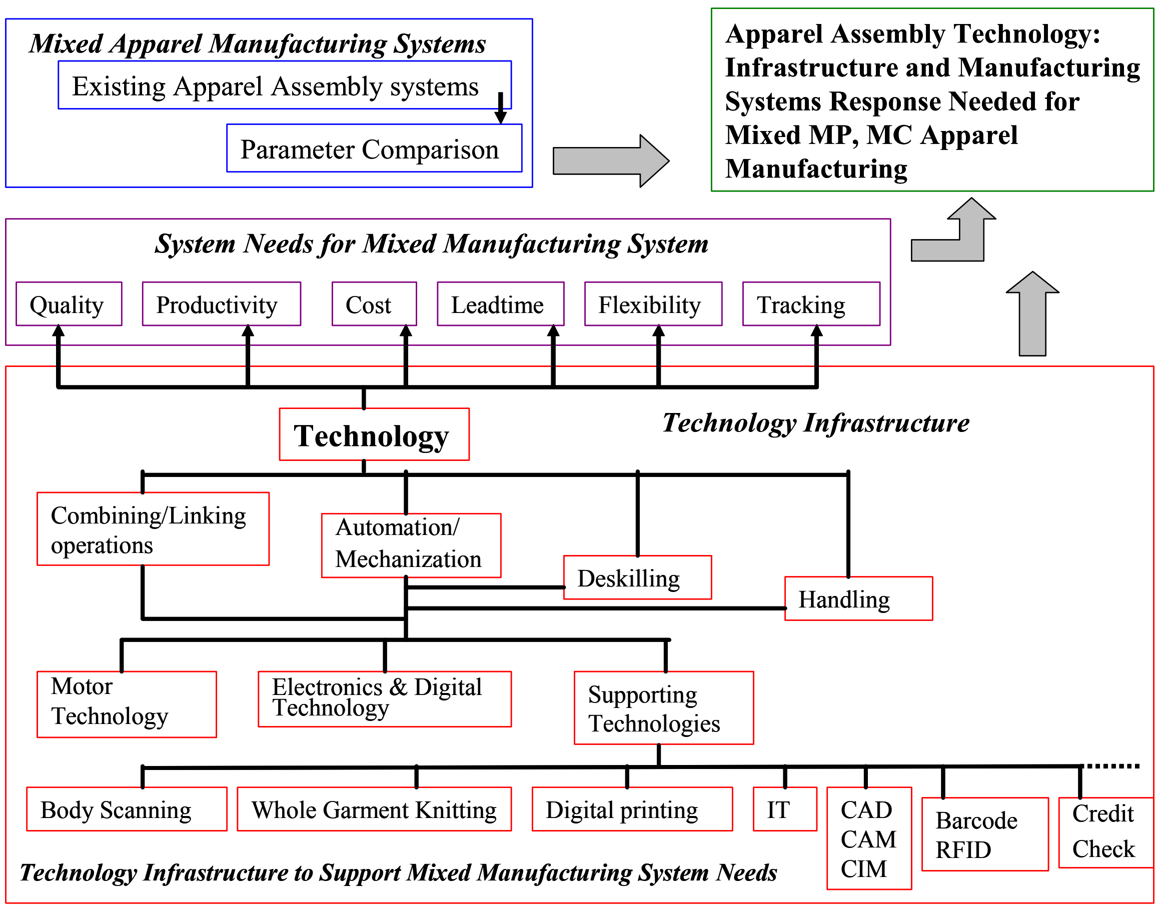

Figure 6.2: Proposed model that address requirements for mixed MP/MC apparel manufacturing

6.1.4 Applicable Technology and Points of Customization

The reviewed literature pertaining to the technology available for apparel MC and the author developed Points of Customization suggest the matrix for apparel MC practice as shown in Table 6.2.

Table 6.2:Applicable technology for Points of Customization

Points of Customization[1]	Applicable Technology
Design Customization	CAD, Whole garment knitting
Fabrication Customization	CAD Digital printing Wholegarment knitting
Fit Customization	Body-Scanning CAD (plus additional Marker/Cutting systems)
Feature Customization	CIM Assembly technology Production systems Wholegarment knitting Embroidery Finishing technology Digital printing
Post Production Customization	Embroidery Finishing technology Digital printing

6.1.5 Mass-Customization - Principles Matrix

Author developed the Table 6.3.which discusses the principles and techniques that are used for mass customization and some related examples from the apparel industry.

[1] See Chapter 4: Points of Customization

This information is vital for the reader to understand the principles and techniques that are used for product MC in relation to apparel practice.

Table 6.3: Principles, techniques and examples for Points of Customization

Points of Customization	Principles/techniques for customization	Description/Examples
Design	Modularity, Variety reduction, Part standardization	Limited offering of design (ex jeans)
	Adjustable customization	Reversible jacket
	Virtual modularity	Ex: Customer selected clothing and accessories fit on to a virtual model. Customer can order as kits such as a blouse, a skirt and cosmetics for the kit
	Hidden modularity	Obtain shirts, ties separately and boxed and pack in to a single package. Obtain shirts and jerseys from two suppliers and pair together to sell as one pack.
	Customization from forecasted parts inventory	Yarns from forecast and knit to order
Fabrication	Modularity Variety reduction Supply chain simplification	Limited fabric offering
	Standardization	Standardized sewing thread, fabric types, colors etc
	Delayed product differentiation	Cut and keep interlinings
Fit	Adjustable	User control manual adjustment. Ex: waist band adjustment of a pair of pants using the band button attachment, swim suits, caps, footwear, athletic wear, gloves
	Dimensional	Pattern alteration for individual fit
	Part standardization, Modularization Reduce variability	Limit fit to a limited extent (Ex: S,M,L)

Table 6.3 (continued)

Feature	Modularity, Variety reduction, Part standardization Delayed product differentiation	Modular parts such as collars & cuffs Limited feature options offerings Parts cut and keep and assemble as requested
Post production	Modularity Postponement Delayed product differentiation Customization from forecasted parts inventory	Modules of garments to be customized after production Athletic apparel customize from stocks. Denims washed as per customers request

6.2 SIMULATION RESULTS AND ANALYSIS

6.2.1 Strategy 1: Integrating MC Product into MP System - PBS

This is to examine with the use of TC^2 TeamMate®, how a MC product impacts a MP manufacturing system when it is mixed with the MP. However, first we want to understand the behavior of a MP system in simulation.

6.2.1.1 Behavior of a MP system (Benchmark)

The Figure 6.3 shows the PBS performance (operator utilization - % time processing) with the bundle variation for MP simulation runs for 1, 3, 4 and 5 days. As shown in Figure 6.3, as the bundle size gets larger, the performance of the production system drops considerably in steps with the changing bundle size. Due to the simulation tool's capacity constraints, simulation runs could not be achieved for some bundle sizes for 5 days of running. It can be seen that with increasing days of production, the system stabilizes for higher performances. Investigating this perturbation is important in moving into the mixed MP/MC manufacturing simulation to reduce the noise due to bundle size variation and simulation duration.

This variation in performance can be due to both bundle size variations within the single bundle size as well as the variations among the bundle sizes. When the variation among bundle sizes is concerned, the stepwise performance drop may be due to the insufficient time to reach the steady state production with the larger bundle sizes.

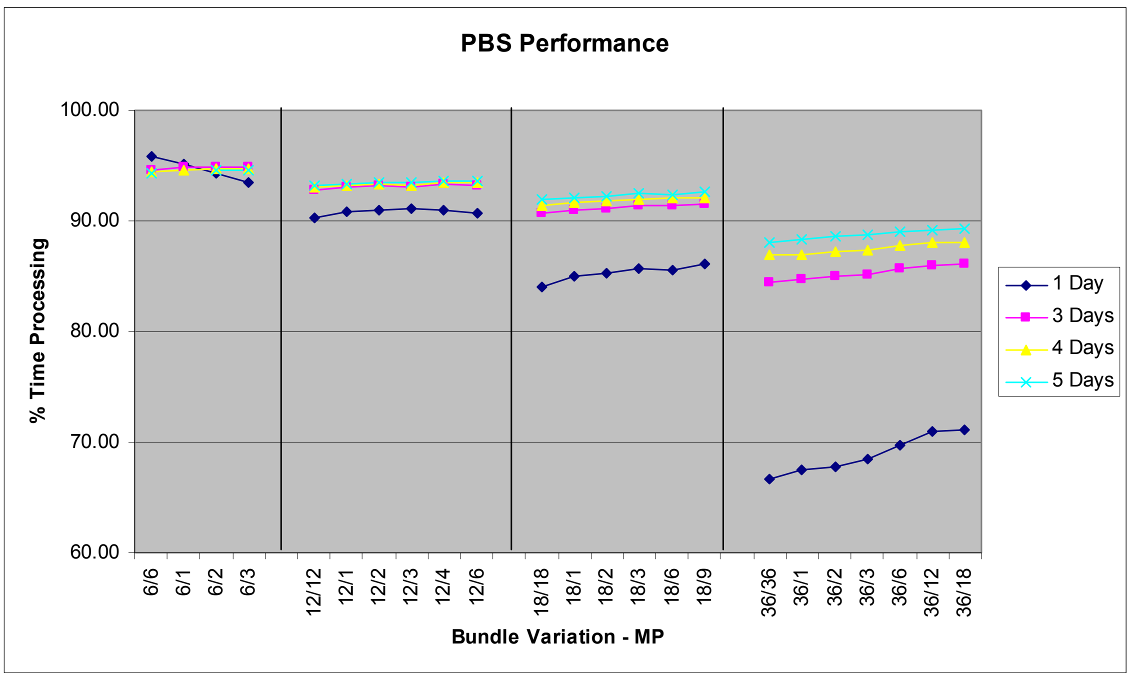

Figure 6.3: Performance variation with bundle size for MP-1, 3, 4, and 5 days run (One style)

As the Figure 6.3 illustrates, it is important to investigate the performance variation with respect to;

- Production duration or simulation runs – days
- MP bundle size

- Alternating bundle sizes for MP

Simulation Duration:

- When the production run of 1-Day is considered, bundle size 6's have a performance level of 94%-96% compared to 12's of 90%-91%, 18's of 84-86% and 36's of 67% - 71%. As the bundle size gets to 36's there is a rapid drop in the performance.
- For 3-Days of simulation, the performance of bundle size 6's is very much similar to one day run. However, the performance of 12's, 18's and 36's have improved with 36's being the highest improvement respectively. At the end of 3-Days production the 36's have a performance range of 84% - 86%.
- Even though the performance improvement of 6's, 12's and 18's are not apparent, 36's have a significant improvement in performance with 4-Days of simulation. This pattern is continued even for 5 days of production where 36's attains a performance range of 88-89%.

MP bundle size:

- When the bundle size variation and the manufacturing system performance are considered, it can be seen that there is a overall performance drop as the bundle sizes change from 6's to 36's.
- If 4-Days production run is considered as maximum for producing mass-customized products, it can be seen that bundle size 6's have a performance of about 94%, bundle size 12's have a performance of about 93%, bundle size 18's

have a performance of 91-92% and bundle size 36's have a performance of 86-88%. This shows a higher performance drop for bigger bundle sizes when moving from one bundle size to the next. The increasing performance within bundle size 36 is most likely due to the added performance associated with the bundle size 6, 12 and 18.

- Moving from bundle size of 6's to 36's, an overall 9% performance drop is seen (4-Days production run). However, when the 1-Day production run is analyzed this performance drop is very much higher than of a 4-Day run performance drop. Therefore, it can be concluded that the performance variation due to MP bundle size is influenced by the production duration.
- Based on the literature, companies expect higher performance with larger bundle sizes as they operate the plant on a continuous basis. However, this manufacturing simulation is different from the normal industry practice of using a single bundle size.

Alternating Bundle Size:

- When the alternating bundle size variation is considered, the 6's (6/1, 6/2, and 6/3) and 12's (12/1, 12/2, 12/3, 12/4 and 12/6) performances have no significant changes within a given production run (for example 4-Days run). The bundle size 18's have less than 1% performance difference (increment moving from 18/1 to 18/9) whereas 36's have a little more than 1% performance increment, considering the same 4-Days production run.

- It can also be noted that this performance variation (noise) within alternating bundle sizes stabilizes with the increase in production duration.
- Therefore, the performance variation due to alternating bundle sizes is considered to be practically negligible when longer production duration is used.

It is important to note that this is not a normal manufacturing practice since it is difficult to track/handle differently sized bundles in a PBS system.

The effect of production duration is further shown in the Figure 6.4. The performance stabilization can be clearly seen with higher the number of days of production run.

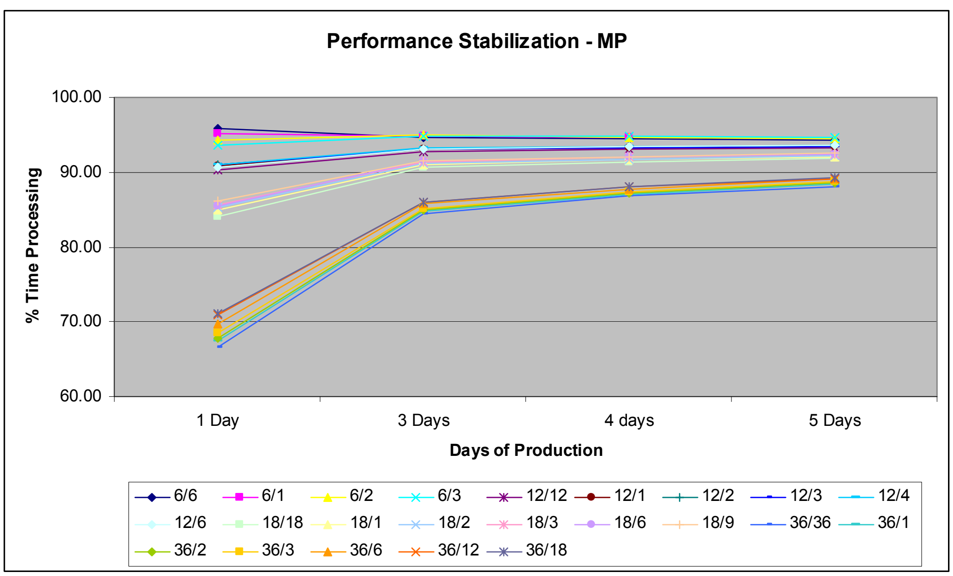

Figure 6.4: Performance stabilization with production duration for MP

Presumably, if the manufacturing system is simulated for 1-2 weeks, the performance will continue to increase as it is found in PBS practice of a 2-week TPT[1]. However, for mass-customized apparel, the main emphasis is on Rapid Response Manufacturing of 1-3 days useful TPT. The current industry benchmarks for the MC are discussed in the Survey Analysis.

6.2.1.2 Mixed MP/MC Manufacturing - Integrating MC Product into MP System – PBS

With the knowledge of the behavior of the MP PBS, mass-customized products are now integrated into the PBS. Figure 6.5 illustrates the PBS performance for mixed MP and mass-customized apparel manufacturing for 1, 3, 4 and 5 days of simulation runs. Each point in the graph shows the manufacturing system performance which is a result of a corresponding simulation run. MP and mass-customized apparel are mixed with base MP bundle sizes of 6, 12, 18 and 36. For each MP bundle size, the volume of customized apparel is increased to explore the system behavior.

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[1] See Chapter 3: Measures for New Product Development

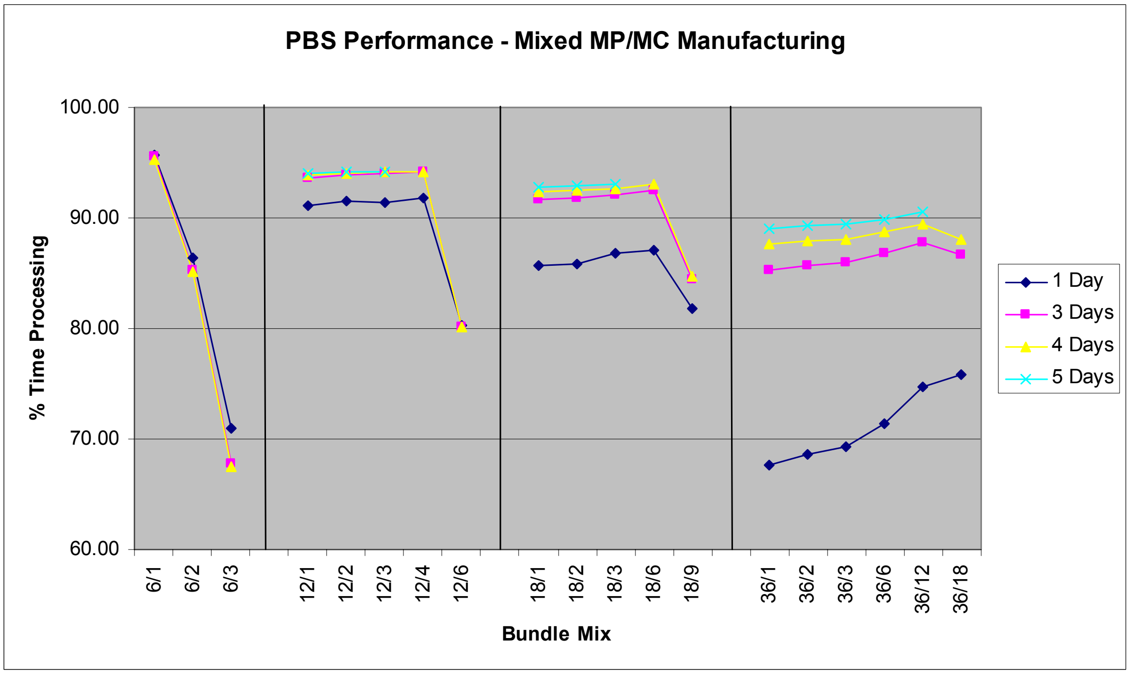

Figure 6.5: PBS performance for mixed MP/MC manufacturing (2 styles)

As illustrated in the Figure 6.5, some pattern exist in the results in relation to number of production runs, MP/MC bundle size variation and alternating MP-MC-MP-MC bundle size variation which are discussed as follows.

Production duration or simulation runs – Days

- As shown in Figure 6.5, when the results pertaining to simulation duration are considered, the MP/MC bundle size 6's behave in a significantly different pattern compared to the MP bundle size 6's. The MP/MC bundle sizes of 12's, 18's and 36's have a similar pattern to the MP performance pattern except a performance drop of the last (MP-MC) mix of each bundle size (such as 12/6, 18/9, and 36/18) which was not apparent in MP system behavior. This is further illustrated in Figures 6.6 and 6.7 for 1 and 3-Day simulation runs.

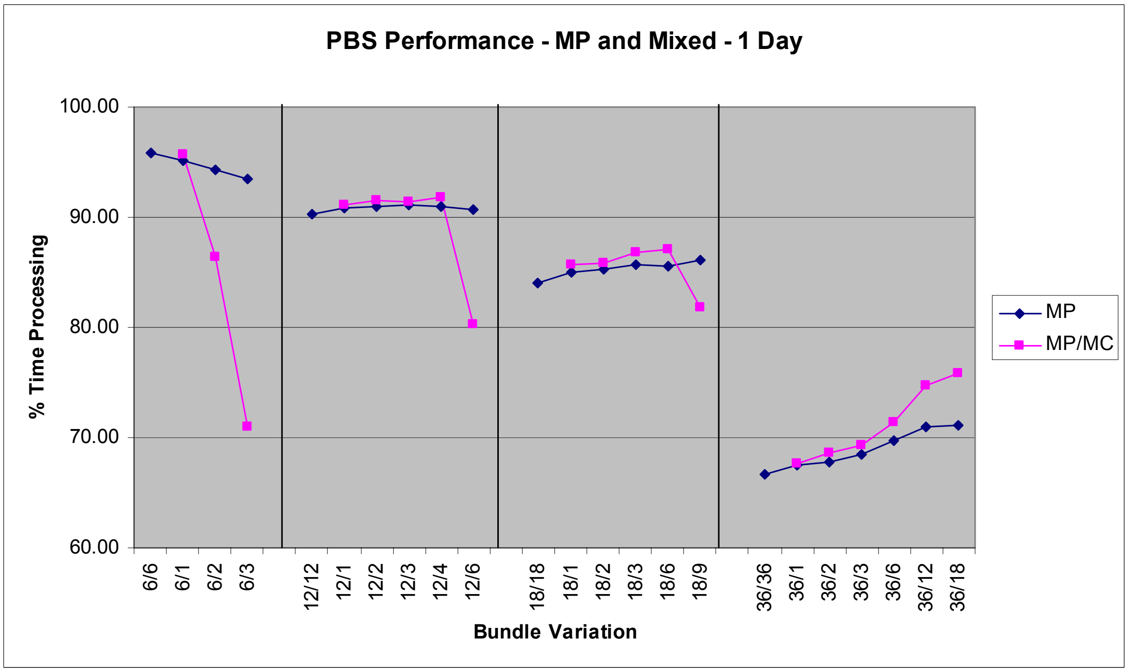

Figure 6.6: MP and Mixed MP/MC comparison, 1-Day simulation run (2 styles)

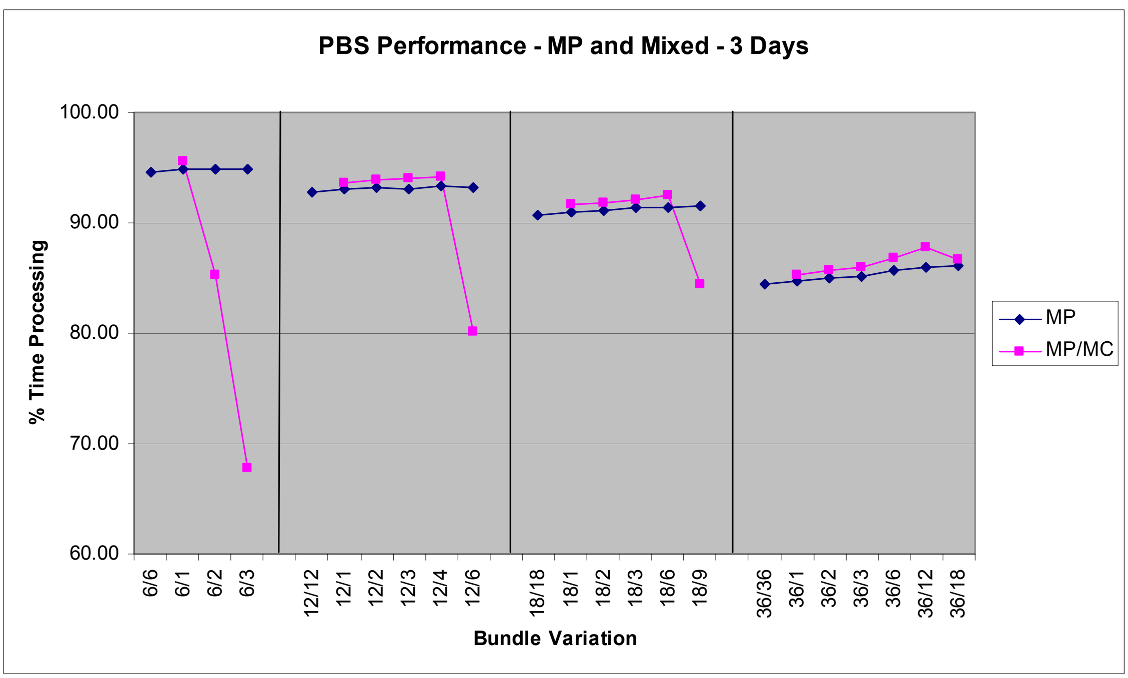

Figure 6.7: MP and Mixed MP/MC comparison, 3-Day simulation run (2 styles)

- When 1- Day production run is considered, bundle size 6's have a 25% performance difference between the 6/1 and 6/3 bundle mix compared to about 11% performance difference among 12's, about 5 % performance difference among 18's and about 8% performance difference among 36's.
- Performance variation for 3 and 4-Days (Fig. 6.7 & 6.8) simulation runs shows a similar pattern stabilizing the performance. The bundle size 6's have about 28% performance difference between the 6/1 and 6/3 bundle mix compared to about 14% performance difference among 12's, about 8 % performance difference among 18's and about 3% performance difference among 36's.

To further discuss the characteristics of the mixed MP and mass-customized manufacturing system, 4-Day production simulation is used as shown in the Figure 6.8. This is considered as the optimum situation. Figure 6.8 illustrates the comparison of MP manufacturing and mixed MP/MC manufacturing performance with the MP bundle and MP/MC bundle mix variation.

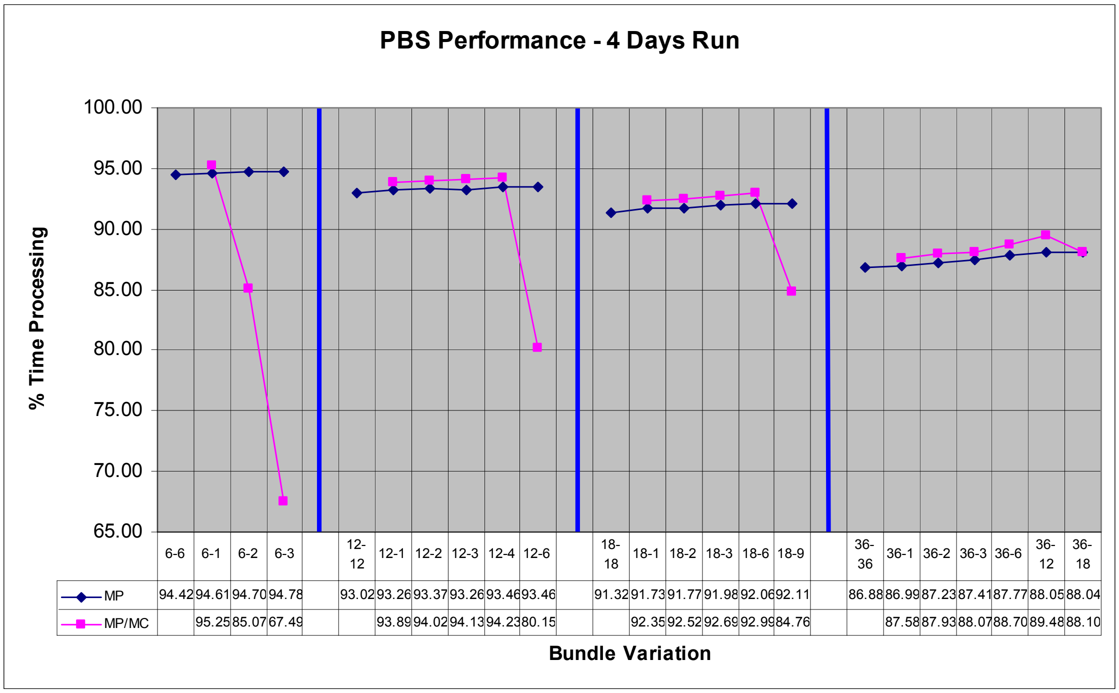

Figure 6.8: Manufacturing system performance-MP and mixed MP/MC comparison

Mixed bundle size:

- When the bundle size variation and the manufacturing system performance is considered, it can be seen that there is a overall performance drop for the bundle sizes moving from 6's to 36's. The performance varies from about 95% for 6's, 93-94% for 12's, 91-92% for 18's and 85-87% for 36's. This is in addition to the drastic performance drop in the last bundle mix of each bundle size (ie 6/3, 12/6, 18/9 and 36/18).
- However, as shown in Figure 6.8, these performances are even slightly higher than the corresponding MP performances
- This drastic performance drop decreases, as the MP quantity of the MP/MC bundle size gets larger. For example, the performance drop from 6/2 to 6/3 is

about 18%, 12/4 to 12/6 is about 14%, 18/6 to 18/9 is about 8% and 36/12 to 36/18 is about 1%.

- Even though the MP system has a performance drop when moving from one bundle size to the next, the mixed MP/MC system offers a greater performance gain if the factory changed, for example, from a bundle size of 6 to a bundle size of 12. This is due to the drastic performance drop of the 6/3, 12/6, 18/9 and 36/18 MP-MC combinations.

Variation due to alternating MP-MC bundle size:

- As discussed before, the performance variation of mixed MP/MC manufacturing for the bundle size mix of 6's has a significant pattern compared to the rest of the bundle sizes. As the mass-customized volume increases (6/1 to 6/2 to 6/3), the performance drops drastically.
- The rest of the bundle sizes, 12's, 18's and 36's show a similar pattern with the increasing number of mass-customized volume. As the mass-customized volume increases, the performance improves at an increasing level when moving from 12's to 36's, i.e. for bundle size 12's the performance difference is 0.34%, for bundle size 18's the performance difference is 0.64%, and for bundle size 36's the performance difference is 1.9%.

The results suggest that if the volume of customized apparel orders is very low, it is viable to use small bundle sizes with low customized unit mix (such as 6-1 [16%] in relation to 6-2 [33%]), but as the demand of customized orders become larger, the simulation indicates that it is better to increase the bundle size of MP (for example, it is better to move to bundle size of 18's if demand for customized mix>12-4). However, when a larger bundle size is selected the cycle time needs to be considered and based on the leadtime (promised for customized product) available the action needs to be balanced. This simulation results provide information for a shirt manufacture who plan to mix mass-customized shirts into the PBS to strategically approach the bundle size with the increase of the customized apparel demand. In addition, these results also provide the MP manufacturer a way to strategically decide on the bundle size for MP shirt manufacturing.

The processing times (SAM) for the shirt operations were obtained for a specific bundle size and the same values were used irrespective of the bundle size for the simulation. Also, the line was balanced with the assumptions specified in Chapter 5, i.e. bundle handling elements were included in the simulation.

6.2.2 Strategy 2: Integrating MP Product into MC Manufacturing System: Kanban Production Line.

This is to examine how MP product impacts the MC production line when it is mixed with the MC. Figure 6.9 shows the MC line performance and the mixed MC/MP line performance with the changing levels of MC/MC or MC/MP style mix. As explained in Chapter 5, the production unit moving in the line is a single garment. Each point in the graph represents a Kanban production line performance value corresponding to simulation run with the respective MC/MC or MC/MP product mix. As shown in Figure 6.9 the MC/MP mix is arranged on the X-axis with increasing volumes of MC style for each MP bundle size.

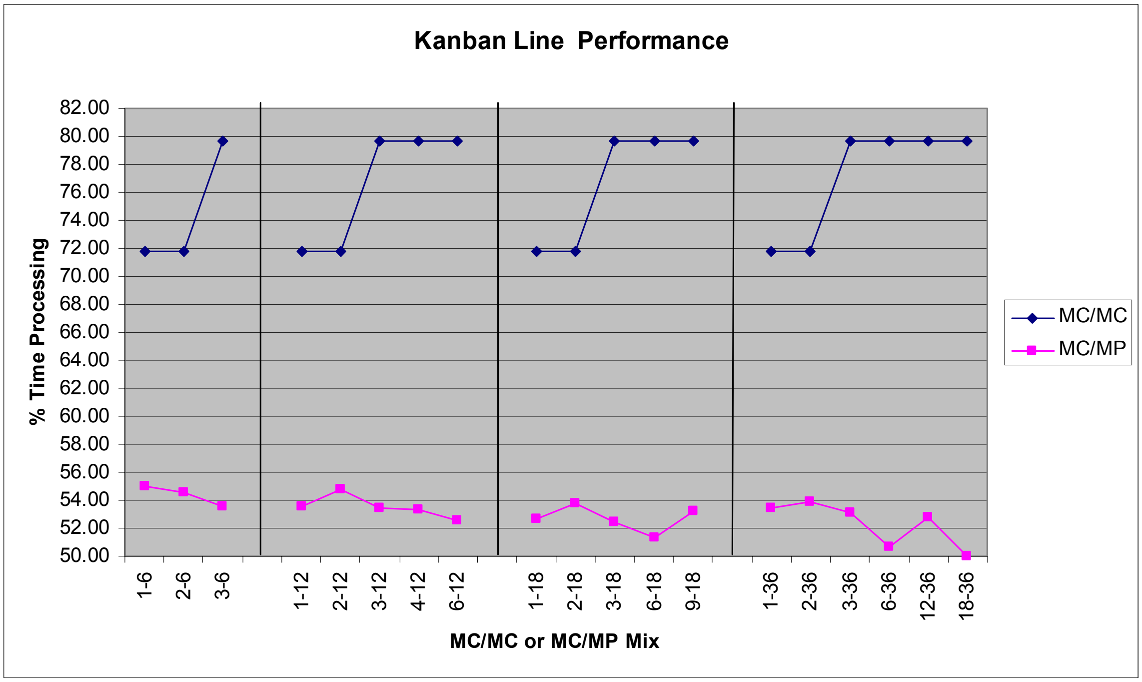

Figure 6.9: Kanban line performance: MC (1 style) and mixed MC/MP (2 styles) production

6.2.2.1 Mass-customized Kanban Line

- When the Kanban production line that produces mass-customized products is considered, a similar pattern of performance variation can be observed across the changing MC-MC product mix with second lot sizes of 12's, 18's and 36's. As only 3 simulation trials were available for the MC-MC mix of lot size 6, it can be seen as a slight variation compared to the other three lot sizes, 12,18 and 36.
- It is evident that the performance increases from 72% to 80% when the first MC lot size of the MC-MC mix increases 3 units or above.
- The line is significantly insensitive to changes when the first lot size of the MC-MC mix is 1 or 2 across all the second lot size 6's, 12's, 18's and 36's.

6.2.2.2 Mixed MC/MP Kanban line

- As Figure 6.9 shows, there is a drastic performance drop when the MC and MP styles are mixed.
- The Performance of the line fluctuates within 50 – 55% across the MC/MP style mix. This line is significantly robust even with the low performance.
- The line performance variation across lot sizes of 6’s, 12’s, 18’s and 36’s has different patterns which are not consistent across all the lot sizes. However, the average performance decreases from lot size 6’s to 36’s (6’s: 54.3%, 12’s: 53.5%, 18’s: 52.7% and 36’s: 52.3%).
- A performance pattern exists for MC lot size volume increasing from 1 to 3 for the MC/MP lot sizes 12’s, 18’s and 36’s which is illustrated in the Figure 6.10. It shows that moving from MC lot sizes from 1 to 2 gains performance and from 2 to 3 loses performance across bundle sizes 12’s, 18’s and 36’s.

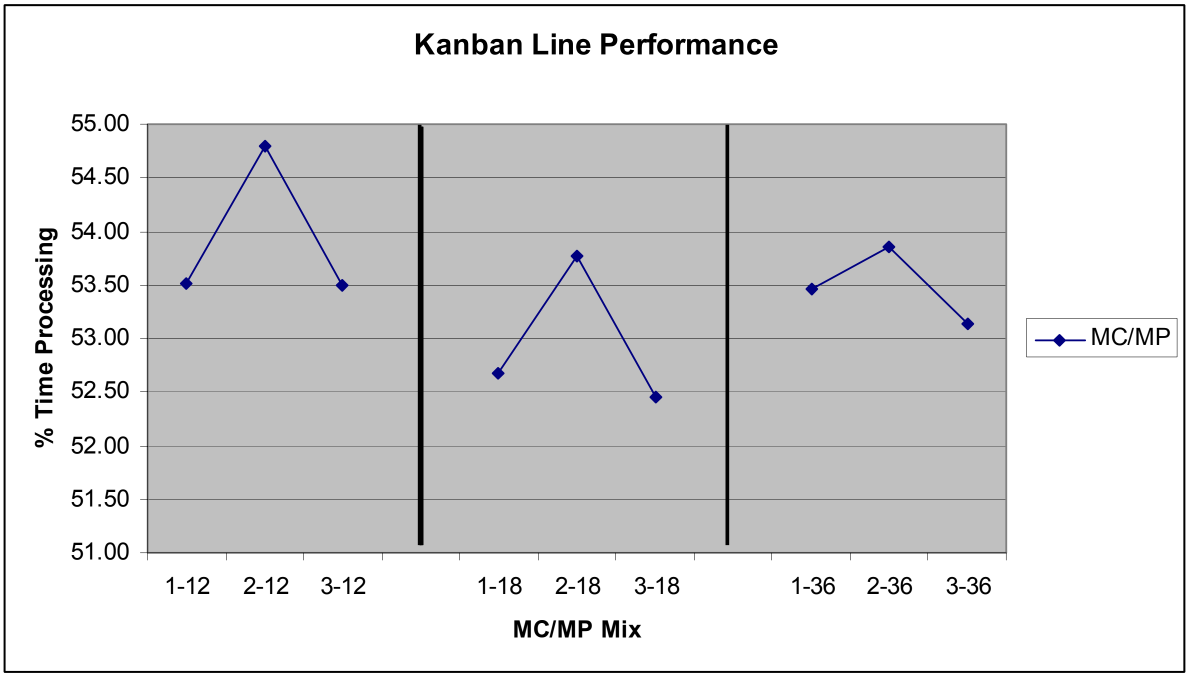

Figure 6.10: MC/MP line performance for MC lot sizes 1,2 and 3 across MP bundle sizes 12, 18 and 36

As the performance for the mixed MC/MP kanban line based on the simulation results was below the expected levels, the same line was evaluated with modeling a MP line and introducing the MC style.

6.2.3 Strategy 1: Integrating MC Product into MP System – Kanban Production Line.

This is to examine how MC product impacts the MP Kanban line when it is mixed with the mass-customized style. Figure 6.11 shows the MP line performance and the mixed MP/MC line performance with the changing levels of MP-MP or MP-MC units. The production unit moving in the line is a single garment. Each point in the graph represents a Kanban production line performance value corresponding to a simulation run with the respective MP/MP or MP/MC product mix.

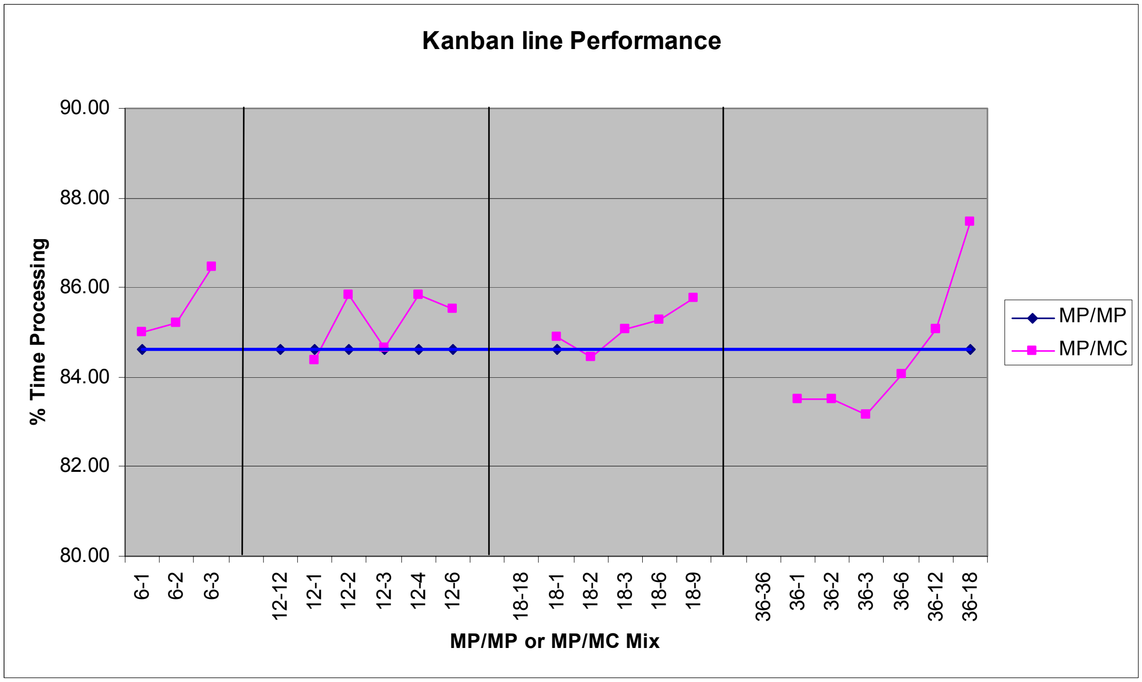

Figure 6.11: Kanban line performance: MP (1 style) and mixed MP/MC (2 styles) production

- As shown in the Figure 6.11, the Kanban MP/MP line is highly robust with the change in lot sizes. The MP/MP Kanban line has a constant line performance of 84.6% across all the lot sizes. This is due to the demand pull system that allowed one piece at each Kanban before the previous operator starts to work. This is an expected result from a Kanban line. However, adding a new style with extra workstations creates patterns of line performance depending on the use of the extra station.

- The MP/MC Kanban line shows an inconsistent performance variation pattern across the bundle variations. However, for the bundle sizes of 6's, 12's and 18's the system performs at an equal or a better level comparing to the MP/MP performance.
- For MP bundle size 36's, the line performance starts at a lower level than MP line performance up to 6 MC units but improves for 12 and 18 MC unit mix.

6.3 SURVEY ANALYSIS

The survey was sent to 24 companies and 16 responded with a response rate of about 67%. Results from the survey instrument are analyzed in three phases. In Phase one the research hypothesis; possibility of mixing MP and MC in apparel manufacturing is addressed. The industry practice information is used to analyze the four methods of manufacturing practice (defined in the survey instrument) that will be repeatedly used in building a relationship with Phase two and Phase three analysis. In Phase two, the proposed research hypothesis that addresses the Points of Customization is tested using the industry information. The Points of Customization and the Extents of Customization are analyzed. In addition, the Feature Customization practice is further analyzed using the four manufacturing practices to explore the relationships that are required to evaluate the manufacturing simulation. In Phase three, the remainder of the information is analyzed, compiled, and presented to provide a detail picture of the current industry practice of Mass-Customized apparel manufacturing.

The companies participated have various business approaches. Disclosed information and further research of these companies have provided the following.

- Companies that customize for individual customers: These companies have a business practice that is mostly e-commerce based or with a physical interaction with the customer to deliver the product within a short time.
- Companies that customize with corporate apparel: Company representatives interact with the customers to obtain and provide information and customized apparel.
- Companies that maintain customized working wardrobes with the span of individual customer to multiple customers as a business unit.
- Companies that customize products with mass produced apparel by providing the service of customized logos, emblems, names, etc.

6.3.1 Company Profiles that Practice Mass-customized Apparel Manufacturing

Figure 6.12 explains the average annual sales of the companies that participated in the survey according to their mass production and mass-customized apparel manufacturing business portions. The sixteen companies are denoted with the letters from A to P.

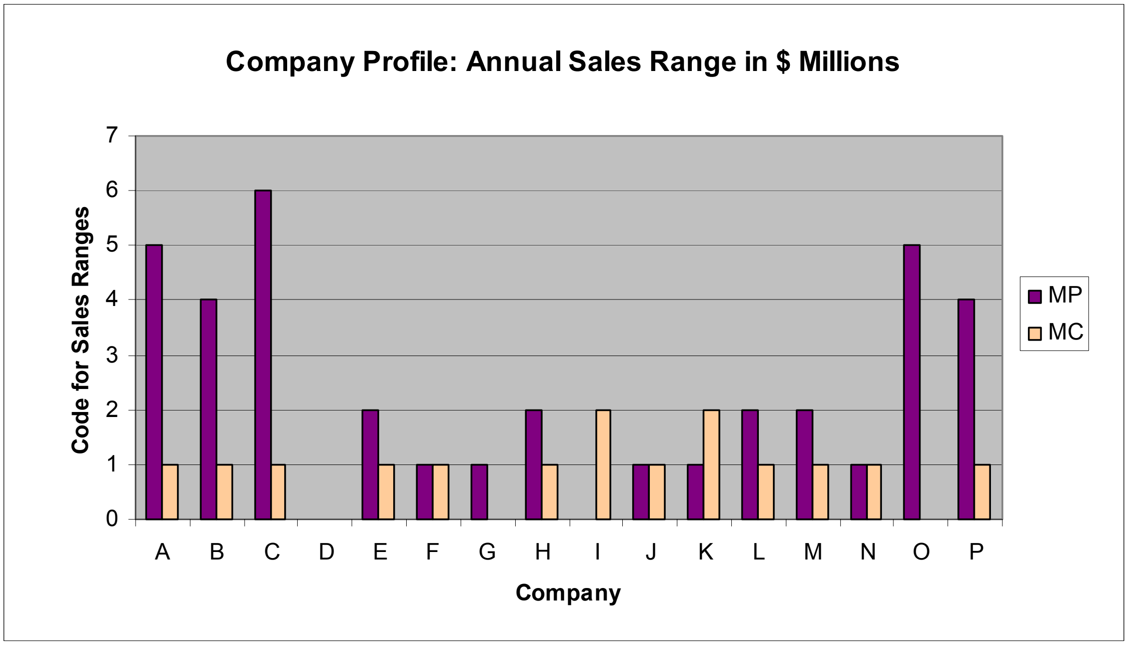

Figure 6.12: Annual MP and MC apparel sales

Table 6.4: Code for sales ranges

Sales	Code
<10M	1
10-50M	2
50-100M	3
100-200M	4
200-500M	5
500-1000M	6
>1000M	7

The code (1 to 7) which is used in the chart is explained by the Table 6.4. It is apparent that all the companies that have responded practice MP sales level of $ 10 million or higher while the MC sales do not exceed $10 million range. This is further explained by the Figure 6.13. As shown in Figure 6.13, 63% of the companies have MC sales less than $ 10 million and about 13% of the companies have $ 10-50 million. 25% of the companies have not disclosed their annual MC sales. When MP sales are considered about 50% of the companies have annual sales less than $ 50 million. 19% of the companies have not disclosed their MP sales. This information of apparel MC business size is contrasting to business models such as Dell Computers which indicates that apparel MC business has not grown as other industries.

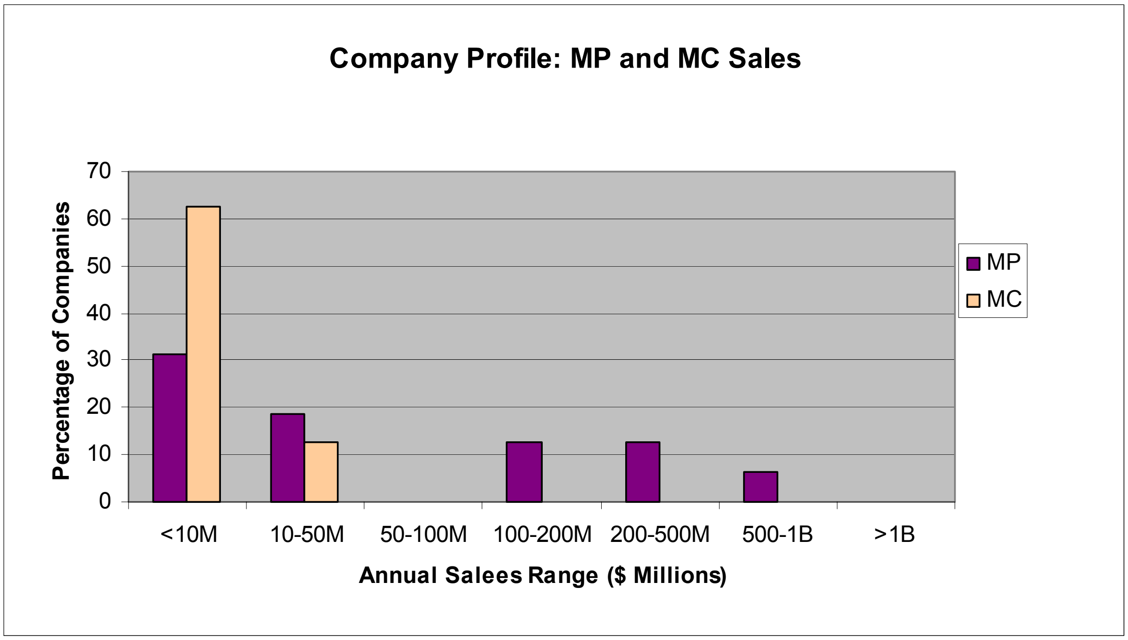

Figure 6.13: Size of the firms and percentage of MP and MC practice

6.3.2 Apparel Product Categories

The Figure 6.14 shows the company profiles in relation to the apparel categories manufactured based on the information gathered by the companies that participated in the survey. Men's and women's tops, men's bottoms and outerwear are the most popular categories for MC apparel that are practiced by about 44% of the companies. 37% of the companies manufacture women's bottoms and 31% of the companies produce accessories. It is apparent that the practice of manufacturing boy's and girl's apparel for MC is limited. In addition the limited practice of innerwear and swimwear for MC may be due to the difficulty in customizing the fit. One of the firms that responded manufactures customized dresses.

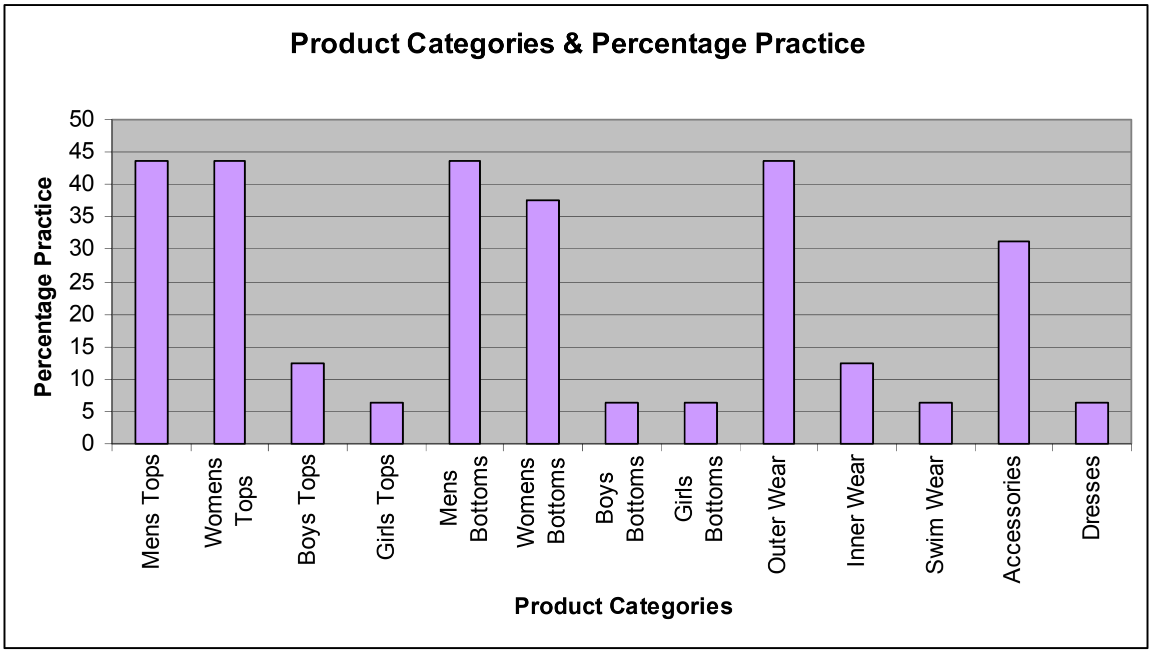

Figure 6.14: Apparel products and percentage industry practice

6.3.3 Industry Practice of MP and MC Apparel Manufacturing

The survey instrument researched four industry practices and corresponding information with regard to the mixed manufacturing of MP and mass-customized apparel. These four Practices are:

P1. Manufacturing both MP and mass-customized apparel in the same production unit

P2. Manufacturing MP and mass-customized apparel in separate production units

P3. Mass production and then customize which also can be interpreted as post production customization and

P4. Mass-customized production only

Table 6.5 shows the number of companies that use the four manufacturing Practices. About 32% of the companies mix MP and mass-customized apparel in the same production units while 26% manufacture in separate production units. 21% of the companies customize products that are already mass produced. 21% of the firms that participated in the survey use only mass-customized apparel manufacturing Practice. It must be noted that with the exception of three firms, all the other firms practice only one of the above Practices. Those three firms employ both P1 and P3. This information provides the fact that 81.25% of the firms use only one method of the above mentioned MP and MC Practices and 18.75% of the firms has multiple approaches to mixed MP and MC.

Table 6.5: Industry Practice of MP and MC apparel manufacturing

Manufacturing Practice	Number of Firms	%
MP/MC same line	6	31.58
MP/MC separate lines	5	26.32
MP & customize	4	21.05
MC only	4	21.05

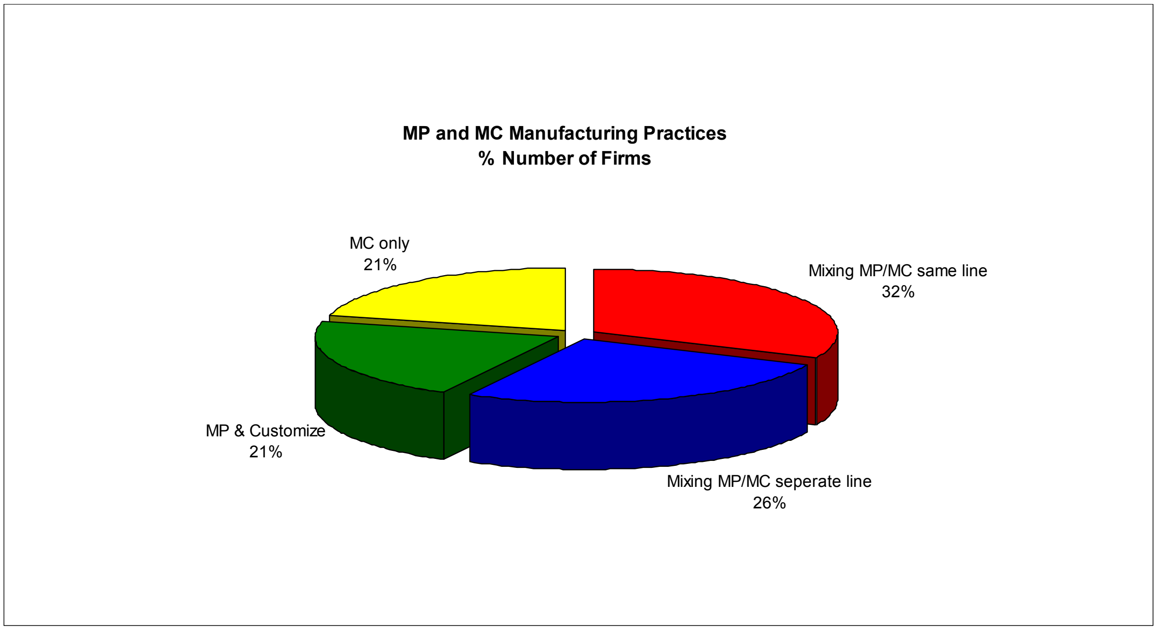

Figure 6.15: Industry practice of MP and MC mixed manufacturing

Figure 6.15 shows the graphical representation of the percentage manufacturing Practice. It is apparent that about 79% of the firms manufacture both MP and customized apparel, out of which 53% of the firms have a mixed manufacturing approach. This industry information provides sufficient evidence for the validation of the mixed manufacturing simulation research approach discussed earlier.

Table 6.6: Industry Practices of MP and MC apparel manufacturing

Firm	Mix Method	Mixed Production				Mass Production					Mass Customization				
		System	Efficy %	Production Unit	Unit Size	System	Efficy %	Production Unit	Size	Made to Order/ Forecast (M,F)	System	Efficy %	Production Unit	Size	Order
A	1	Bundle Individual incentive line	88	MP-Bundle MC-Single	12 1	Bundle	88	Bundle	12	M+F	Bundle	88	Single	1	MTO
F	1,3	UPS	88	MP-Single MC-Single	1 1										
J	1	Make Through/ Modular Seated (future)		MC-Single	1										
K	1,3	Bundle	105	MP-Bundle MC-Bundle	36-72 36-72						Bundle	105	Bundle	36-72	
M	1	UPS	120	MP-Single MC-Single	1 1										
B	2					Line	80	Bundle	20	M+F	Line	40	Single	1	MTO
H	2					Bundle UPS	100 100	Bundle	24	Combined M+F	UPS	60	Single	1	MTO
N	2					Bundle	99	Bundle	24	F	Line	100	Single	1	MTO
P	2					UPS	60	Single	1	F					
O	3					Bundle		Bundle							
C	4										Bundle Modular/ Stand-up		Bundle-Parts Single-After	Vary 1	
G	4										Bundle	Hourly Paid	Bundle	Vary	MTO
I	4										N/A, Accessory for sourced garments only				MTO
L	4	Line Bundle		MP-Single MP-Bundle MC-Single MC-Bundle	Vary Vary Vary Vary						Line Bundle		Single Vary	1	MTO

The compiled responses from part of the section C of the survey[1] instrument which consists of the manufacturing Practice (1,2,3 and 4 options as shown above), production (sewing) system, average system efficiency, production unit that moves in the line, unit size, and order method (made-to-order/forecast) are shown in Table 6.6. The data is also shown under the main three sections of the survey instrument (section C1-mixed production, C2-MP and C3-MC) that was routed by color coded method based on the initial response for manufacturing practice (4 options). As shown in Table 6.6, the companies are named with letters and has sorted out based on the manufacturing Practice. Two companies did not disclose the manufacturing information. Companies F and K responded claiming that they Practice both mixed production in the same (P1) line and MP followed by customization (P3).

- Mixed Production - Same Line (P1):

The companies which Practice mixed production (P1) use a wide variation of manufacturing systems. The Bundle System and UPS are used by 80% of these companies. Company A uses a Line System in addition to the Bundle System for mass-customized apparel. The efficiencies range from 88% to 120% while bundle size varies from 12 to 72. The bundle sizes of 6, 12 18 and 36 and the Progressive Bundle production system that was used for mixed production computer simulation approach in this research is supported by the industry practice information. Company J claimed that it used a Make Through System at the time of the survey but will switch to the seated

[1] See Appendix C1: Survey Instrument

Modular System. Out of the 5 companies, only one company has responded with the order method; made-to-order (MTO) or Forecasting for MP and MTO for MC.

- Mixed Production - Separate Lines (P2):

The responses from companies that Practice mixing of MP and MC production in separate sewing lines are shown with P2 (Mix Method=2) in the Table 6.6. 40% of these companies use Bundle System for the MP with a bundle size of 24 and operating at efficiency around 100%. These companies use forecasting and combined forecasting and made-to-order methods for order initiation. Another 40% of the companies use UPS as the MP manufacturing system, operating with efficiencies of 60% to 100% and forecasting as the order initiation method. 10% of the companies use Line System for MP with a bundle size of 20, operating at 80% efficiency and use both forecasting and made-to-order as method of order initiation. Line System with efficiencies of 40% to 100% and UPS with efficiency of 60% are used for the MC lines with made-to-order as the order initiation method.

It is apparent that companies which use bundle system for the MP use Line System with a single unit size or UPS for the MC manufacturing. The efficiencies of the MC manufacturing systems in almost all cases are lower than the MP manufacturing systems. This industry information validates the MP and MC mixed manufacturing simulation efficiencies used by the author in the computer simulation approach.

- Mass Production and Customization – Post Production Customization (P3):

As shown in Figure 6.15, 21% of the total companies practice this method of MC where Bundle System and UPS are used. Company K is a good example for this type of MC practice which uses large bundle sizes and achieves higher efficiencies, then follows customizing the product. The relationship of these manufacturing Practices and the extent, points or nature of customization that is practiced by the companies will be addressed later in this Chapter.

- Mass Customization Only (P4):

21% of the companies practice this approach where Line, Bundle and Modular systems are used as manufacturing systems. Manufacturing is carried out with made-to-order method of order initiation. Some companies also use Bundle System to manufacture small parts followed by a stand-up Modular system for assembly.

The summary of all the manufacturing systems used by companies to practice apparel MC, is shown in Table.6.7.

Table 6.7: Manufacturing systems used in MC of apparel

Manufacturing System	% Practice
Bundle	44.4
Line	22.2
UPS	22.2
Modular	11.1

As Table.6.7 illustrates, the UPS and Modular system use a single garment as the unit moving in the production line. In addition as Table 6.6 shows, the Line system uses a single unit when it practices MC. Unit size of one is an important requirement for mass-customized apparel manufacturing especially when it is required for complex Feature Customization. The Bundle System is the most common system followed by UPS and Line Systems. Even though these four systems are used in the industry, two systems have been used during the simulation for the dissertation research.

6.3.4 Manufacturing Practice and Extent of Feature Customization

The points of customization for apparel as introduced by the author are Design, Fabrication, Fit, Feature and Post Production customization[1]. Out of these, most influential customization for the manufacturing process is the Feature Customization. Figure 6.16 shows the industry practice in relation to the four manufacturing practices and their corresponding extent of Feature Customization that affects the manufacturing in assembly. The cells are colored based on the manufacturing Practice and respective Feature Customization.

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[1] See Chapter 4: Points of Customization

Company	Mix Method	Feature Customization - Assembly Point				
		Construction	Emblems, Logos, Prints, Photos	Ornamental Stitching	Monogram	Other (applicable for assembly)
A	1					
F	1,3					
J	1					
K	1,3					
M	1					
B	2					
H	2					
N	2					
P	2					
O	3					
C	4					
G	4					
I	4					
L	4					

Figure 6.16: Industry practice of manufacturing and corresponding extent of Feature Customization at assembly Point

- Mixed production – Same Line (P1):

The companies who practice the mixed MP and MC in the same line practice customization Features vary widely. It is apparent that the most common customization Features are emblems, logos, photos and prints which are practiced by 80% of the companies. 60% of these companies customize apparel with construction Features and 40% of them customize with ornamental stitching, monograms and other methods. An example for “other method” as per the company responses, is the side seam or waist band adjustment for a pair of jeans. Due to the fact that it is difficult to operate a production system to manufacture wide variation of MP and MC styles in the same line, all the companies practice the mixed system with non complex customization operations such as emblems, logos, monograms, ornamental stitching and minor construction changes.

- Mixed Production - Separate Lines (P2):

As it can be seen that 75% of the companies who practice separate lines for MP and MC, customize their apparel products with construction Features. This is because of the capability of addressing the complex construction differences of MP and MC in separate lines. 50% of the companies use monograms and 25% of the companies use emblems/logos/prints/photos, ornamental stitching and other features.

- Mass Production and Customization – Post Production Customization (P3):

Company	Mix Method	Feature Customization - Assembly Point				
		Construction	Emblems, Logos, Prints, Photos	Ornamental Stitching	Monogram	Other (applicable for assembly)
F	1,3					
K	1,3					
O	3					

Figure 6.17: Extracted from Figure 6.16

Figure 6.17.shows the relationship of the industry practice of Feature customization to the third manufacturing practice as explained in number 3 (P3) above. As the Figure 6.17 depicts, all the companies use emblems/logos/prints/photos features to customize which is a common practice for this method of customization. Two thirds of the companies use monogramming and construction Features while one third of the companies use ornamental stitching and other Feature customization. The construction Feature customization must allow the flexibility of production processes to be carried out

after the primary MP process. Companies use processes such as shortening, lengthening, and adding pockets for construction Feature customization.

- Mass Customization Only (P4):

Out of the four companies which produce apparel only for mass customization, only three firms have responded for the Feature customization questions. It is apparent that all these three firms use only monogramming and emblems/logos/prints/photos Feature customization. This finding considerably contradicts with the general expectation from a company which produce only for mass customization in relation to Feature customization. But the reason may be that they practice other customization extents such as Design, Fit, Fabrication and Post Production which are not discussed here. However, these companies have the opportunity to implement Feature customization further with construction, ornamental stitching and other features based on the product, manufacturing system and business expectations.

6.3.5 Points and Extents of Mass-Customization

The critical Points of MC and the Extent of MC that were developed in the Hypothesis section of the dissertation are tested with the industry practice. Each Point of Customization and their Extent of Customization are analyzed. The survey instrument assisted in identifying whether there are any other industry practices for the Points of Customization other than what author has developed based on the available literature in both apparel and non-apparel industries that practice MC.

6.3.6 Points and Extents of Mass-Customization Practice

Figure 6.18 shows the industry practice of Points of Customization as a percentage of the total sample size.

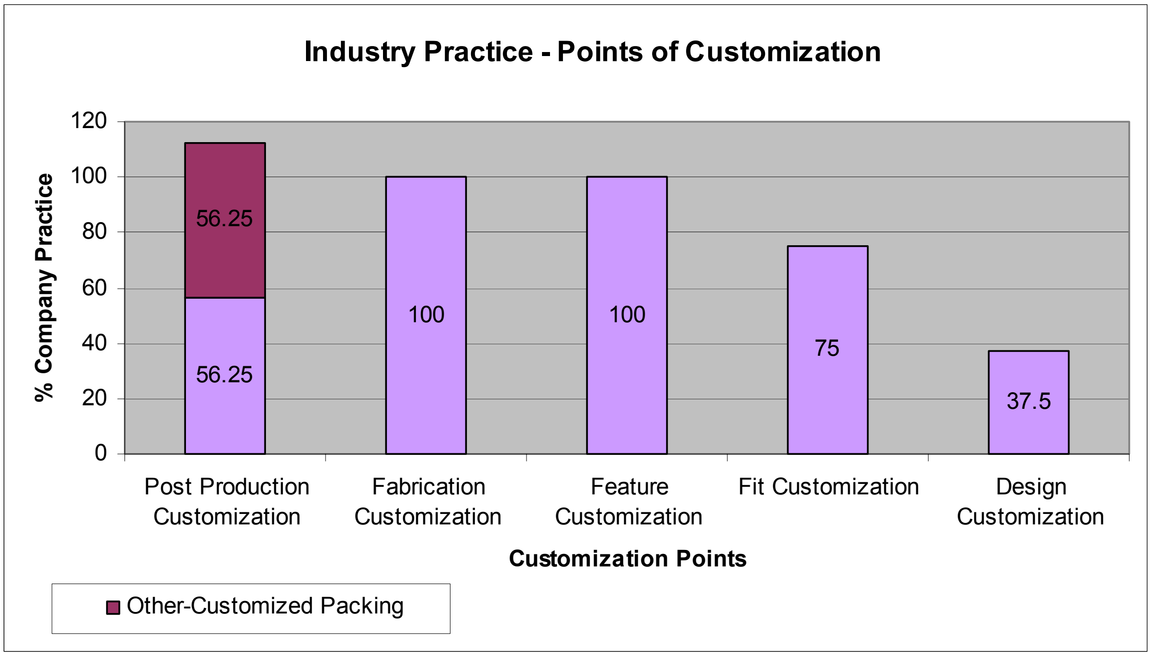

Figure 6.18: Industry practice model for Points of Customization

Customized Packing (for example, customized labels, hangtags, boxes, etc) is an additional customization extent which falls under the Post Production Customization that was discovered from the survey and is shown as an addition to the primary customization points. Addition of these two extents make the Post Production Customization the highest industry practiced Point of Customization. Almost all the firms that practice MC use Fabrication and Feature customization. 75% of the firms use Fit Customization and 37.5% of the firms that practice MC use Design customization. This is most likely due to the complexity of the manufacturing operation caused by offering the customer to make decisions on designing the product. These customization points are further analyzed for the industry practice by breaking down to extents of customization as discussed below.

6.3.6.1 Extent of Fabrication Customization Practice

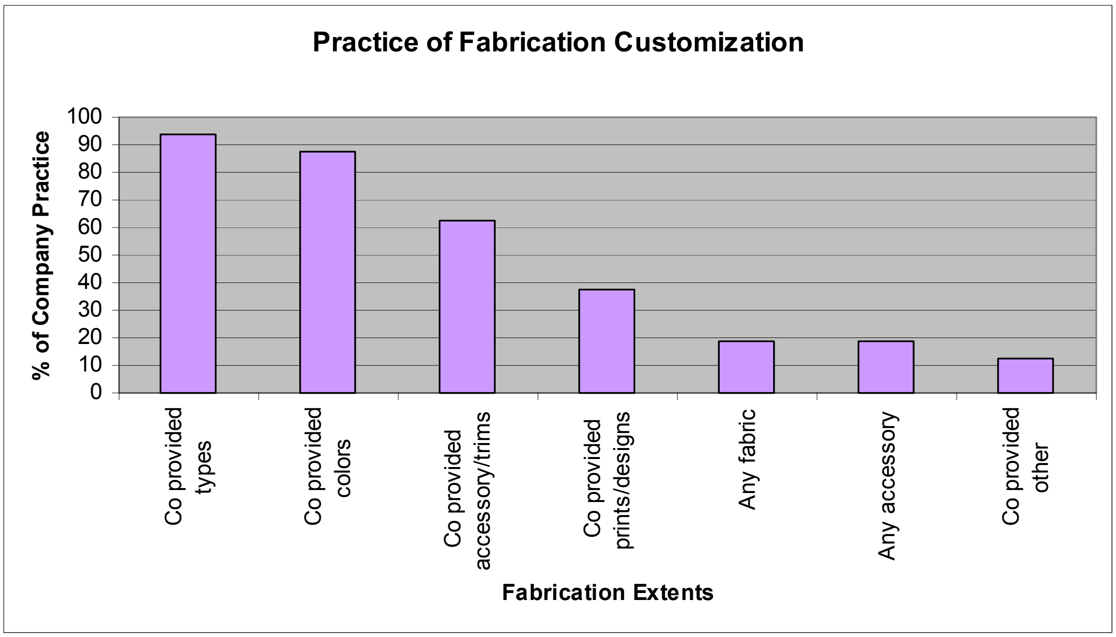

Figure 6.19: Industry practice model for Fabrication Customization

The Figure 6.19 describes the industry practices of Fabrication Customization which is discussed with its customization extents. The extents of Fabrication customization are discussed with any fabric or accessory for higher end customization to company provided fabric, accessory or other Fabrication materials at lower end customization in the Fabrication customization continuum. The idea behind the term "company provided" is that, the customer is given the choice to select from the company offered fabric types, fabric colors, accessories, fabric prints and designs. The terms "any fabric" or "any accessory" means that the customer can virtually decide his/her own fabric or accessory for the product but usually it is limited to the available material in the inventory. An examples for "company provided other" is a fabric finish offered by the company. As clearly shown in Figure 6.19, the industry practice of high-end Fabrication customization such as "any fabric" or "any accessory" is about 19% compared to most companies' common practice of "company provided fabrics"(94%) and "company provided fabric colors" (87%). About 62% of the companies offer accessory options and about 38% offer fabric prints/designs options for MC.

6.3.6.2 Extent of Feature Customization Practice

The Figure 6.20 shows the Point of Feature Customization industry practice which is illustrated with its Extent of Customization. The industry practice of customization Features such as "monograms", "emblems/logos/prints/photos (ELPP)", "construction", "washing/finishing" and "other" are discussed with customization options provided by the company or specified by the customer. Ornamental stitching is another customization Feature that is researched with the survey instrument. The responses from companies indicate that a "company provided other" Feature can be waist band adjustment for jeans and a "customer specified other" can be special finishes requested by the customer.

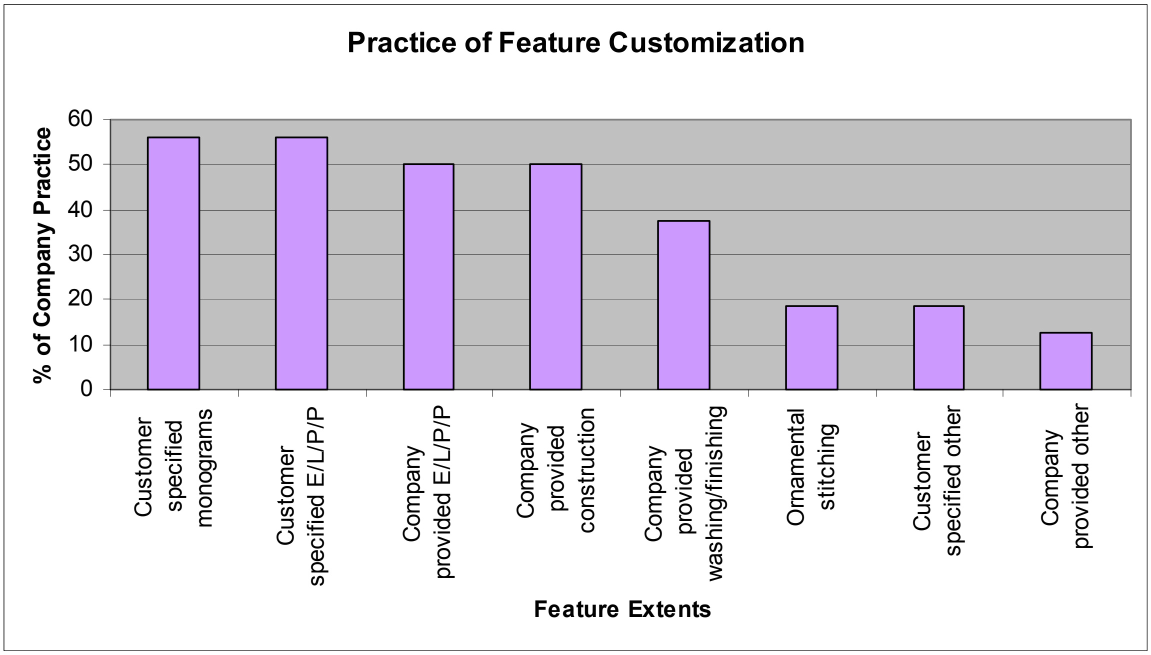

Figure 6.20: Industry practice model for Feature Customization

As shown in Figure 6.20 customer specified features such as monograms and E/L/P/P leads with 57% of the companies practice Feature Customization. As the customer has the opportunity to demand the features, this practice has a higher extent of customization compared to the company provided E/L/P/P and construction features which is practiced by 50% of the companies. About 19% of the companies practice ornamental stitching and other customer specified features while 13% practice other company provided features for MC. The simulation approach in the dissertation consider Feature Customization, particularly the customer specified monogramming which is the major industry practice and hence validate the simulation approach.

6.3.6.3 Extent of Fit Customization Practice

The industry practice of Fit Customization which is another important Point of Customization is explained by the Figure 6.21. The methods of obtaining the measurements for fit customization are shown as the extent of fit. Measurements taken from body scanning is considered as a fit extent at the higher end whereas general fit options offered by the company is of a lower end fit extent.

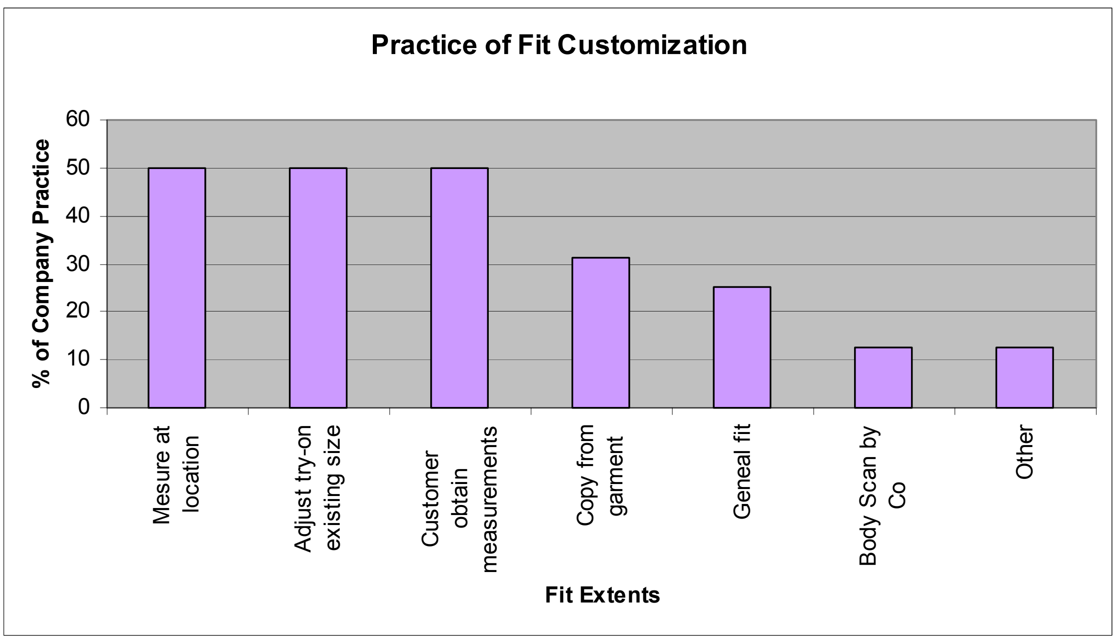

Figure 6.21: Industry practice model for Fit Customization

Fit Customization using measurements taken at the store/location by the sales associate, customer obtained measurements as instructed by the company and making fit adjustments by customer try-on an existing size appear to be practiced by most companies (50%). 31% of the companies use the practice of copying the measurements from customer provided garment and 25% of the companies customize fit using general fit descriptions. Examples of general fit descriptions can be “relaxed fit” and “regular fit”. Even though the body scanning technology is expected to be used by many companies who practice Fit Customization, it is being used by only 13% of the MC companies. Customization fit using sales people who visit customers to obtain measurements and providing the customer with guidelines to select the appropriate size are the responses that was received under the “other” category of the Fit customization extent which is practiced by about 13% of the companies.

6.3.6.3.1 Practice of Pattern Making and Alteration for Mass-Customization

The survey instrument was equipped to gather information on pattern procedures whether to make new patterns or to modify the existing patterns during the process of mass-customized apparel manufacturing. Figure 6.22 illustrates the percentage of firms that practice new pattern making or existing pattern modification based on their manufacturing practice.

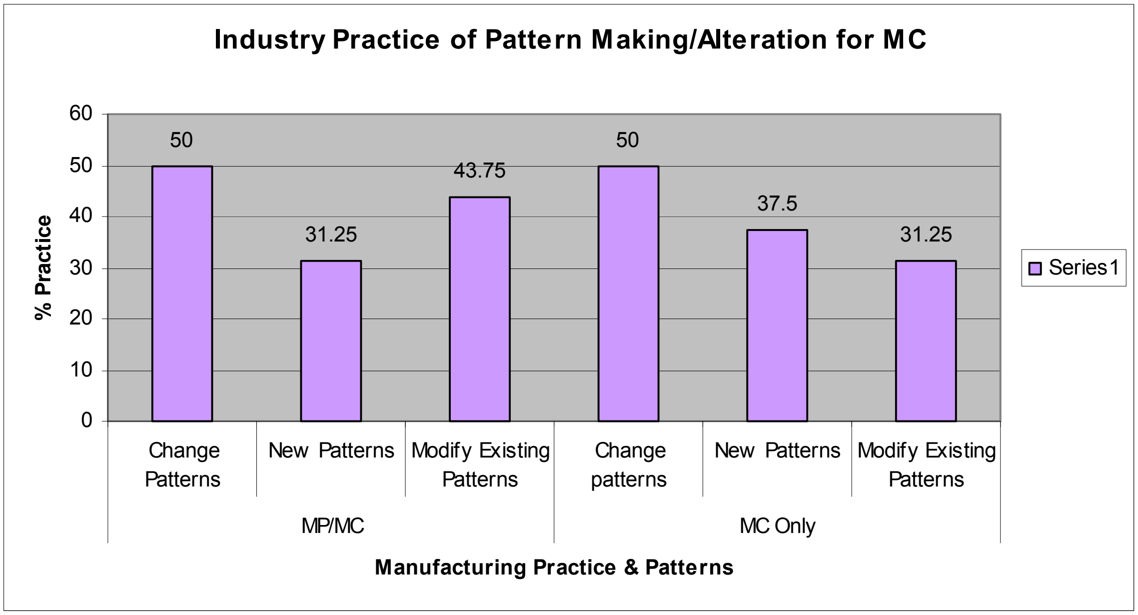

Figure 6.22: Industry practice of pattern making or alteration based on manufacturing practice

Fifty percent of the firms that practice mixing of "MP and MC in the same production line" manipulate patterns for Fit Customization out of which about 31% make new patterns and 44% alter existing patterns. Also, 50% of the firms that practice "MC only" manipulate patterns out of which about 38% make new patterns and 31% modify existing patterns for Fit Customization. With this information it is apparent that more firms alter existing patterns if they practice the MP and MC mixing approach while a higher percentage of firms make new patterns when practicing the "MC only" approach.

Table 6.8: Manufacturing practice and leadtimes for Customization

		Lead Time (Days)											
Company	**Manufacturing Practice**	**Design**	**Fabrication**	**Feature**	**Fit**	**Fabrication & Feature**	**Fabrication & Fit**	**Fit & Feature**	**Fabrication, Feature & Fit**	**PPC From Stock**	**Full Custom**	**Other**	**Other LT**
A	1			20	20			20		5			
E	1,3	90-180		90-180	90-180		90-180		90-180	14			
F	1,3	90	120	30-90	42-90	120	120	42-90	120		120		
J	1	14	14	14							14	Print design, feature design, and fabrication	14
K	1,3		49 to 98	21 to 56	21 to 56	49 to 98	49 to 98	21 to 56	49 to 98	1			
B	2							14					
D	2		21	21	21	21	21	21	21		21		
H	2								15	10			
N	2										21-28		
P	2	24			24	24	24	24	24				
O	3									14			
C	4											Design/FIT/ Fabrication	7 to 10
G	4	45	90		90		90		150				
I	4	2	2 to 10	2	2	7 to 10	7 to 10	7 to 10	7 to 10		5 to 25		

Table 6.9: All companies that use manufacturing practice 3, extracted from Table 6.8

		Lead Time (Days)											
Company	**Manufacturing Practice**	**Design**	**Fabrication**	**Feature**	**Fit**	**Fabrication & Feature**	**Fabrication & Fit**	**Fit & Feature**	**Fabrication, Feature & Fit**	**PPC From Stock**	**Full Custom**	**Other**	**Other LT**
E	1,3	90-180		90-180	90-180		90-180		90-180	14			
F	1,3	90	120	30-90	42-90	120	120	42-90	120		120		
K	1,3		49 to 98	21 to 56	21 to 56	49 to 98	49 to 98	21 to 56	49 to 98	1			
O	3									14			

6.3.7 Mass-customized Apparel Manufacturing Leadtimes

6.3.7.1 Manufacturing Practice and Customization Leadtimes

Table 6.8 and Table 6.9 show the information for the relationship of manufacturing practice and the extent of customization (both individual and combinations) leadtimes. This leadtime is defined as the time that the company offers to customers in their respective MC practice. As illustrated in the Tables, out of the 14 firms that responded to this section, 71% practice customization leadtimes less than 3-4 weeks. As expected, the post production customization (PPC) from stock practice has a shorter leadtime which is less than 2 weeks and in some cases even with a leadtime of a single day, e.g. Company K. When the four manufacturing practices are considered, it is apparent that companies who practice manufacturing MP and MC in separate lines (manufacturing practice,2) have a shorter customization leadtimes and those companies that practice P3 (MP and then customize) have a larger customization leadtimes when compared to the rest of the companies.

6.3.7.2 Manufacturing Practice, Pattern Manipulation and Leadtimes

Table 6.10 illustrates the industry practice of pattern making and pattern alteration and their respective leadtimes based on the manufacturing Practice in mass-customized apparel manufacturing. This leadtime is defined as the time from “order to pattern ready”. The colored cells in the “Change Pattern” raw show the companies that responded claiming to change patterns with the respective manufacturing practice in the mass customization process. Leadtimes to make new patterns range from as fast as few minutes to as much as 10 days and leadtimes for modifying existing patterns range from one hour to 10 days. Except companies G & K, all the other companies practice a leadtime of less than 2 days. From Figure 6.16 it can be seen that both Companies G & K customize features with emblems/logos/prints/photos and monogramming. G & K can be considered as practicing customization from mass production stocks which may explain the longer pattern making and alteration leadtimes.

6.3.7.3 Manufacturing Practice, Marker Making and Leadtimes

Table 6.11 describes the manufacturing Practice of the firms, the marker types and the respective marker making leadtimes. The leadtime is defined as the time between order arrival and marker ready. It is apparent that the leadtime to make single markers for MC ranges from less than an hour to 3 days. Based on the provided information, except the firms F and N, all other firms practice a marker leadtime less than 3 days irrespective of the marker type. It must be noted that company F has longer leadtimes for all the operations including marker making. Company N uses multi-markers for the MP and claims that it does not need markers for MC. Observing the data it is apparent that the marker making leadtimes has a span of as low as few minutes to as large as seven days.

Table 6.10: Industry practice of pattern making/alteration and leadtimes for MP/MC apparel manufacturing

Companies	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Mixed MP/MC - Lead Time: Order to Pattern Ready																
Change Patterns																
New Patterns				1 hour						1 day	10 days	Vary	Depends on backlog and customer need			
Modify Existing Patterns	1day			1 hour	N/A	Depends on modification				1 day	5 days	Vary	Depends on backlog and customer need			
MC Only - Lead Time: Order to Pattern Ready																
Change patterns																
New Patterns		2 days	Immediate/ minutes					1 day	1 to 2 days		10 days			1 day		
Modify Existing Patterns	1 day						10 days		1 to 2 days		5 days	Vary				

Table 6.11: Industry practice of marker making and leadtimes for MP/MC apparel manufacturing

	Companies	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Marker	Mixed MP/MC - Lead Time: Order to Marker Ready																
Multi	MP	2 days					7 days					1 day					
	MC						Hours, depend on modification										
Single	MP				1 hour		7 days				1 hour						
	MC	2 days			1 hour		Hours, depend on modification				1 hour			Depends on backlog and customer need			
Marker	MP - Lead Time: Order to Marker Ready																
Multi	MP	1 hour	2 days				7 days		3 days						7 days		
Single	MP	1 hour					7 days										3 days
Marker	MC - Lead Time: Order to Marker Ready																
Multi	MC											1 day	Varies		No marker needed		
Single	MC	1 day	1 day	Instantaneous				3 days	2 days				Varies				

6.3.7.4 Manufacturing Practice, Cutting Systems, Technology and Cutting Leadtimes

Table 6.12 illustrates the industry practice of cutting systems, the technologies use and the leadtimes with respect to the manufacturing Practice for MP and mass-customized apparel manufacturing. The leadtime here is defined as the time from "marker ready to finish cutting". A higher percentage of firms use single ply cutting system for mass-customized apparel cutting compared to the multi ply cutting system. Both manual and automatic cutting technologies are used where firms use laser and knife technologies in automatic cutting. The leadtime for cutting varies from 2 minutes to 5 days for the mass-customized apparel cutting. However, for MC single ply cutting the leadtime has a span of 2 minutes to 2 days.

6.3.7.5 Manufacturing Practice, Country of Origin and Leadtimes

Table 6.13 shows the responses from the companies for leadtimes from order to finish goods from the country of manufacturing with respect to the manufacturing Practice for MP and mass-customized apparel manufacturing. When MC practice with goods manufacturing in USA is considered, the leadtimes vary from less than a day to 90 days. However, when the companies other than F, G are considered, they practice a leadtime of 28 days or less. Companies that have their manufacturing in other countries, practice a leadtime of 4 to 56 days for MC apparel. It is also important to note the short leadtimes that companies practice in MC with manufacturing taking place in countries such as China, Hong Kong and Dominican Republic which are less than two weeks.

However, when mixed manufacturing in the same units are considered the leadtimes become longer when out sourcing both MP and mass-customized apparel. The leadtimes for mass produced apparel can be 15-30 days from USA but increase when sourcing from other countries such as Mexico, China, Portugal and Colombia. However, 11 day leadtime from Honduras for MP apparel is a successful strategy compared to sourcing from Asia or Europe.

A summary of minimum (Min) and the maximum (Max) leadtimes practiced by the companies for MP and MC apparel manufacturing is shown in the Table 6.14. These values are extracted from the tables already discussed above. This information provides an overview picture of the practiced leadtimes in mix MP and mass-customized apparel manufacturing. According to the minimum leadtimes, it can be concluded that except Companies F and G, other companies has the ability to manufacture customized apparel (order to finish goods) in less than 3 weeks.

Table 6.12: Industry practice of cutting systems, technology and cutting leadtimes for MP/MC apparel manufacturing

	Companies	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
	Mixed MP/MC - Lead Time: Marker Ready to Finish Cutting																
MP	Multi ply	Gerber medium ply					Lectra low ply					NC high		Manual			
	Lead time	2 days					2 days					5 days		2 days			
	Single ply				Automatic		Lectra Laser				Single ply m/c + Manual			Auto			
	Lead Time				1 hour		2 days				1 hour , 2 hours			2 days			
MC	Multi ply						Lectra low ply					NC high		Manual			
	Lead time						2 days					5 days		2 days			
	Single ply	Gerber single ply					Lectra laser				Single ply m/c+ Manual			Auto			
	Lead Time	4 hours					2 days				1 hour , 2 hours			2 days			
	MP- Lead Time: Marker Ready to Finish Cutting																
MP	Multi ply	Gerber medium ply	NC high				Lectra low ply		NC high						Manual		
	Lead time	2 days	3 days				2 days		5 days						2 days		
	Single ply	Gerber single ply					Lectra Laser										
	Lead Time	2 days					2 days									3 days	
	MC- Lead Time: Marker Ready to Finish Cutting																
MC	Multi ply							Manual				NC high			Manual		
	Lead time							1-3 days				5 days			4 hours		
	Single ply	Gerber single ply	NC	CEI automatic				Manual									
	Lead Time	1 day	2 days	2 minutes				1 day	2 days								

Table 6.13: Manufacturing Practice, country of manufacturing and leadtimes

	Companies	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
	Mixed MP/MC - Lead time: Order to Finish Goods																
MP	Country 1	USA					USA				USA	USA		USA			
	Lead Time	25 days					42-90 days				14-21 days	21 days		3 days			
	Country 2											Dominican Republic		El Salvador			
	Lead time											56 days		44 days			
MC	Country 1	USA					USA				USA	USA		USA			
	Lead Time	18 days					42-90 days				28-42 days	21 days		3 days			
	Country 2											Dominican Republic		El Salvador			
	Lead time											56 days		30 days			
	MP - Lead time: Order to Finish Goods																
MP	Country 1	USA							USA								
	Lead Time	30 days							15 days								
	Country 2	Mexico	Dominican Republic												China		Honduras
	Lead time	40 days	28 days												30 days		11 days
	Country 3	Portugal	China														
	Lead Time	70 days	63 days														
	Country 4	Colombia															
	Lead time	60 days															
	MC - Lead time: Order to Finish Goods																
MC	Country 1	USA		USA				USA		USA		USA					
	Lead Time	20 days		< 1 day				90 days		7-10 days		21 days					
	Country 2		Dominican Republic							China		Dominican Republic			Hong Kong		
	Lead time		14 days							7-14 days		56 days			4-14 days		

Table 6.14: Summary of MP and MC manufacturing leadtimes

	Companies	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Order to Marker Ready	Min	1 hour	1 day	< 1 hour	1 hour		Hours	3 days	2 days		1 hour	1 day					
	Max	2 days	2 days	<l hour	1 hour		7 days	3 days	3 days		1 hour	1 day			7 days		
Marker Ready to Finish Cut	Min	4 hrs	2 days	<1 hour	1 hour		2 days	1 day	2 days		1 hour	5 days		2 days	4 hours	3 days	
	Max	2 days	3 days	< 1 hour	1 hour		2 days	3 days	5 days		2 hours	5 days		2 days	2 days	3 days	
Order to Finish Goods	Min	18 days	14 days	<1 day			42 days	90 days	15 days	7 days	14 days	21 days		3 days	4 days		11 days
	Max	70 days	63 days	< 1 day			90 days	90 days	15 days	14 days	42 days	56 days		44 days	30 days		11 days

6.3.8 Industry Business Practice - Distribution

6.3.8.1 Country of Manufacturing, Distribution Practice and Shipping Lead times

Table 6.15 illustrates the practice of shipping lead times from the country of MP and MC apparel manufacturing with distribution practices such as consumer direct, to DC, DC to store, DC to consumer and store direct.

For mass-customized apparel, the consumer direct shipping leadtimes vary from 11 hours to 11 days irrespective of the country of manufacturing. Company F's response of 42-90 days is an invalid data point because based on the response to customization leadtime questions the firm uses 42-90 days in total to supply goods to the customers. For MC apparel, shipping leadtime from manufacturing to DC varies from 1 to 14 days, from DC to store and DC to consumer 1 to 11 days, and store direct 2 to 10 days.

This information provides a good view of logistic capabilities for the firms that are interested in mass-customized apparel manufacturing.

Table 6.15: Industry practice - Logistics

	Companies	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
	Distribution - Country of Manufacture and Shipping Lead Time																
	Country 1	USA	Dominican Republic			UAE	USA	USA	USA	China	USA	USA	USA	USA	China		Honduras
	Consumer Direct						42-90 days	90 days		1 day	2- 5 days	1-2 days	days				
	To DC	2 days	7 days						15 days	Our DC 2 - 3 days		1-2 days		3-14 days	2 days		7 days
	DC to Store	4 days	2 days									1-2 days		2 days	Air-7 days, Sea -4 weeks		
	DC to Consumer											1-2 days					
	Store Direct										2-5 days						
	Country 2	Mexico	China							USA		Dominican Republic		El Salvador			
	Consumer Direct									1 day		11 days					
	To DC	10 days	28 days							Our DC 1 day		11 days		44 days			
MP	DC to Store	4 days	2days									11 days		5 days			
	DC to Consumer											11 days					
	Store Direct																
	Country 3	South America								CBI							
	Consumer Direct									1 day							
	To DC	15 days								Our DC 2 days							
	DC to Store	4 days															
	DC to Consumer																
	Store Direct																
	Country 4	Europe															
	Consumer Direct																
	To DC	25 days															
	DC to Store																
	DC to Consumer																
	Store Direct																
	Distribution - Country of Manufacture and Shipping Lead Time																
	Country 1	US	Dominican Republic	USA		UAE	USA	USA	USA	China	USA	USA	USA	USA	Hong Kong		Honduras
	Consumer Direct		1 day	2 - 4 days			42-90 days	5 days		1 day	2-5 days	1-2 days	days		3 days		11 hours
	To DC	1 day	5 days							Our DC 2 - 3 days		1-2 days		3-14 days			
	DC to Store	2 days										1-2 days					
	DC to Consumer											1-2 days					
	Store Direct			2 days					10 days		2-5 days				4 days		
	Country 2									USA		Dominican Republic		El Salvador			
MC	Consumer Direct									1 day		11 days					
	To DC									Our DC 1 day		11 days		14 days			
	DC to Store											11 days					
	DC to Consumer											11 days					
	Store Direct																
	Country 3									CBI							
	Consumer Direct									1 day							
	To DC									Our Dc 2 days							
	DC to Store																
	DC to Consumer																
	Store Direct																

6.3.9 Industry Business Practice – Costs

6.3.9.1 Assembly, Raw Material and Order Handling Costs

Figure 6.23 shows the percentage response from the firms regarding the assembly, raw material and order handling cost of a mass-customized apparel product in comparison to mass produced apparel product.

As shown in Figure 6.23, 63%, 56% and 75% of the firms believe that the per piece assembly, raw material and the order handling cost has increased respectively compared to MP apparel. This information further confirms the manufacturing cost information that was discussed under the topic “cost and economic advantage of MC” in the Literature review section of the dissertation. The companies that responded with “not relevant” only practice MC apparel manufacturing. It is also important to note the higher cost of order handling in MC as in most cases the product must be individually tracked and handled which is a major emphasis in the mission of mixed MP and MC manufacturing.

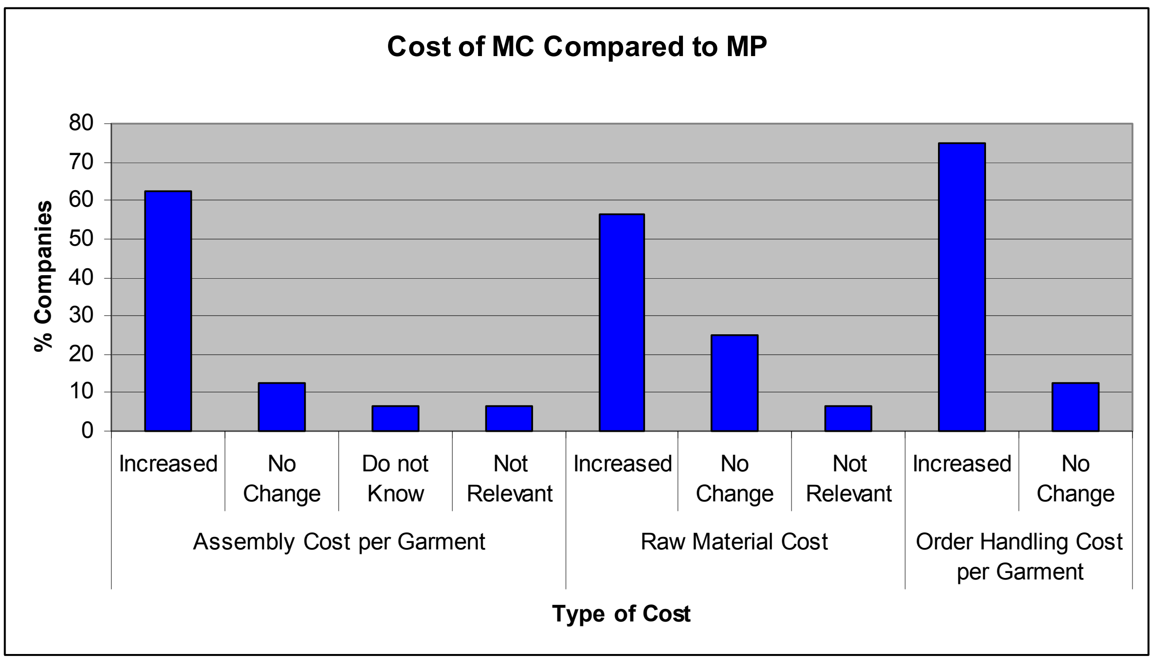

Figure 6.23: Assembly, raw material and order handling cost for MC compared to MP

6.3.9.2 Other Costs

Figure 6.24 shows the other cost types related to MC compared with MP when practice mixed MP and MC apparel manufacturing. As Figure 6.24 shows, greater percentage of the companies agree that except warehousing, WIP inventory and finish goods inventory costs other costs increase in MC compared to MP practice. More than 60% of the companies responded agreeing that the product development and raw material (RM) inventory costs are increased for mass-customized products. The greater percentage of firms agrees that the marketing and sales cost is increased in MC may be due to one-on-one marketing and advertising, etc. Distribution cost is increased for MC apparel due to consumer or store direct shipments of low volumes. Even though about 32% of the companies' warehouse cost has not been changed, about 25% of the companies agree to have this cost increased. Overall, about 70% of the firms agree that the total cost will increase for MC when mixing with MP.

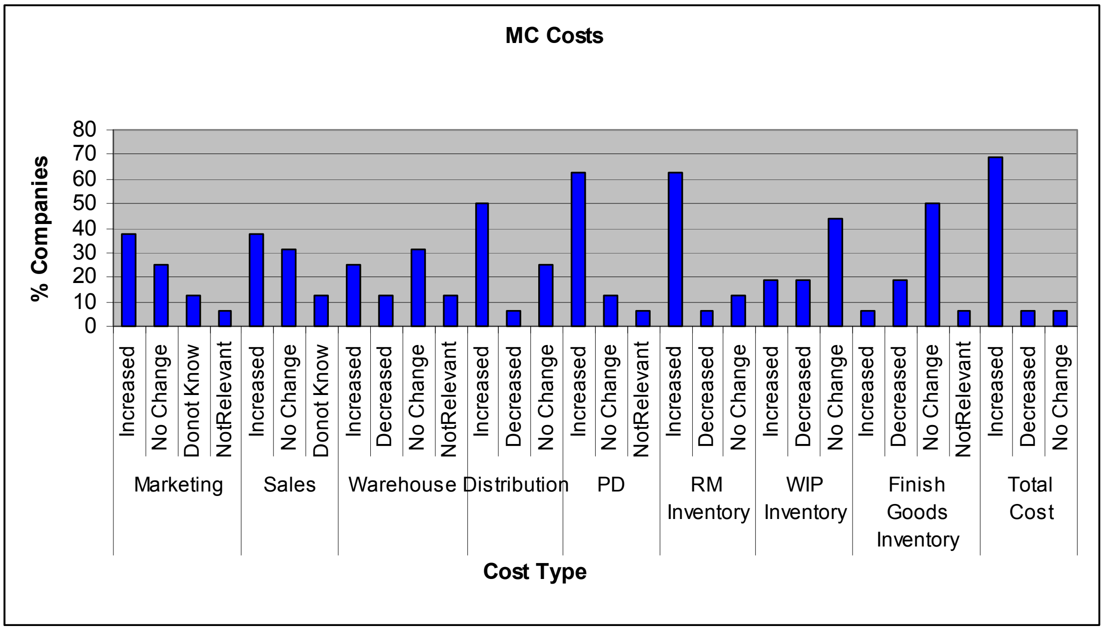

Figure 6.24: Cost changes by function for MC product compared to MP

6.3.10 Mass-Customization Continuum

The model "Levels/Layers of Customization" (Fig. 2.19) discussed under the topic "Extent of Mass Customization and Points of Customization" in the literature review section of the dissertation is analyzed.

To quantify the extent (levels) of customization that was shown in the model from literature, a table with a scale is developed as shown in the Table 6.16.

Table 6.16: Scale to quantify the levels and layers

Scale	1	2	3	4
Design	Mass	Options		Custom
Production	Mass			Custom
Fit	Mass	Mass fit with custom try on to individual	Custom fit	Individual custom fit
Location	Mass	Limited	Choices	
Fabric	Existing		Custom finished	Custom
Styles	Existing	Menu of choices		Custom

Using this scale the model is interpreted as shown in the Table 6.17.

Table 6.17: Level and layer totals based on the scale

Layers	Levels						
Extent/Points	1	2	3	4	5	6	Total
Design	1	2	1	2	2	4	12
Production	1	1	1	1	1	4	9
Fit	1	1	2	2	3	4	13
Location	1	1	2	2	2	3	11
Fabric	1	1	1	3	3	4	13
Style	1	1	1	2	2	4	11
Total	6	7	8	12	13	23	

Figure 6.25 shows how the level totals vary with the MC continuum in relation to the Levels/Layers of Customization model. As the Figure 6.25 illustrates, moving from mass production towards customization does not provide a linear continuum but the extent of customized increment appear to be taken place in steps. However, this result is based on a scale developed by the author based on the elements from Anderson et al (1995). Defining a scale is very complex with the extents of customization. Using this scale, it is apparent that the MC model proposed by Anderson et al (1995) is a nonlinear MC model.

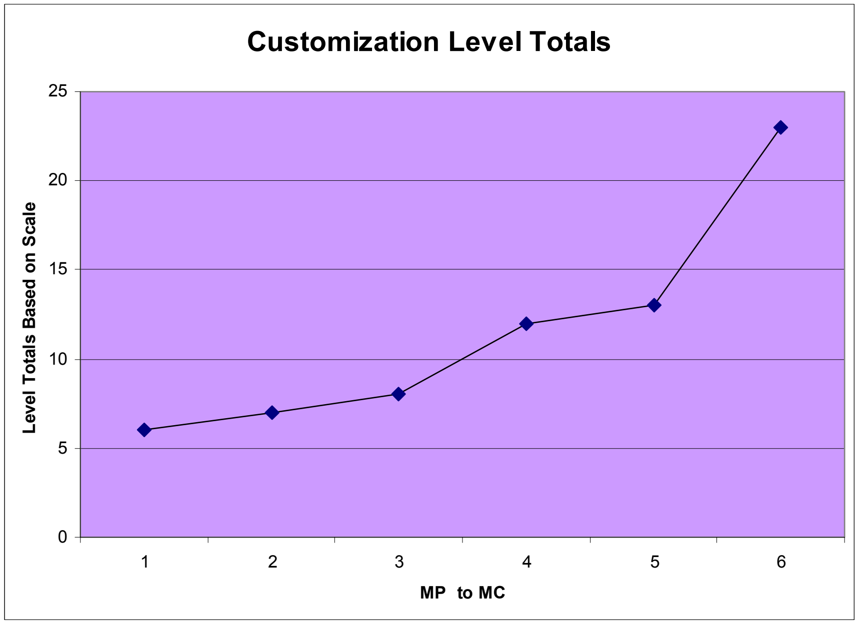

Figure 6.25: MC continuum, non linear model

As seen in the Points of Customization and Extent of these individual Points of Customization, the customization continuum is a complex model. It is difficult to quantify the extents within each Point of Customization. To conclude the MC continuum, further research is proposed.

6.4 Case Study Analysis

This case study was carried out with the company which assisted this research by providing the information for the computer simulation and the industry survey. Due to confidentiality, the name is not disclosed.

The company practices both MP and MC men's shirts manufacturing with annual sales of less than 50 million dollars of MP and less than 10 million dollars of MC. This company manufactures about 500-800 customized shirts and about 700 dozens of MP shirts a week. Customized order turnaround time of 2-3 weeks and MP replenishment TPT of 3 weeks is practiced. A MP order frequency of about 17 and MC order frequency of about 175 is expected for a week.

The company manufactures for 75 retail stores in the U.S. and supply for both MP and MC orders. Customers can either select a mass-produced shirt for the available price or a mass-customized shirt for a comparatively higher price. The design, ordering and execution process for mass-customized shirts is discussed below.

Once the customer enters the retail store the sales associate provides a shirt of a closest size to the customer based on the interested style. Once the garment is fit-on, specific fit measurements are recorded by the associate for correct fit. The Fit Customization options are collar measurements, front and back length measurements, waist taper measurements, and sleeve length measurements. In some situations the customer provides a shirt with a "good fit" for fit measurements.

Customization features as demanded by the customer is then recorded. Company provides the customer specific feature options to be selected from. These Feature

Customization options are for collars, cuffs, sleeves, backs and fronts. In addition some construction features such as edge stitching and monogramming is offered. The monogramming options include color, style and position which is an additional feature that the customer can select. The "placement" can be on the pocket, cuff, front and placket which shows one of the extents of this Feature Customization point. Company maintains about 300 different fabrics from which customer can select for Fabrication Customization. The sales associate enters the design, fit, feature, and customer information into the computer system which is accessible to the manufacturing facility in real time.

The manufacturing facility retrieves the orders from the 75 retail locations every day a number of times. In the pre-production stage, the fit information is compared to the existing size measurements and the required changes are done for the measurements of the style which is closest to the customer request. The made-to-measure software program changes the existing size patterns according to the changes made for the customer fit and a marker is made based on the order size for a particular fabric. The marker is sent to the single ply cutter. A data sheet called a "traveler" is made with the order information which travels with the individual garment through the execution process that is used at each individual process until the order is shipped to the customer. An average leadtime of 2 days is practiced from customer order placement to marker ready.

During the cutting process, an effort is made to cut as much as MC orders from a single fabric type to reduce the handling time. Most of the interlinings are pre-cut and kept in storage for use which is trimmed for required measurements. For orders that need "matching", matching parts are "block-cut". About 125 orders are cut per 8 hour day. From marker to finish cutting, 2 day leadtime is practiced. The required parts are fused with the fusible interlinings. The fabrics are stored expecting orders as the leadtime for fabrics can be 22-26 weeks from overseas.

The cut parts with the "traveler" are loaded on the hanger for the UPS. The workstation route is entered and the hanger is loaded to the UPS. There can be work modules within the UPS that can address the Feature Customization at assembly. Each workstation is loaded with thread cones of different colors to be used based on the information provided by the "traveler". Multi skilled operators are used where appropriate to balance the line for varying operation times. Based on the information provided by the "traveler", operators execute the sewing operation appropriately. A sewing leadtime of 1 day is practiced where from finish cutting to finish sewing, a leadtime of 2-3 days is practiced. An efficiency of 100% is expected on average from the UPS.

The completed garment with the "traveler" is transferred to the finishing and packing department for final operations. Once the order is complete, it will be shipped to the store. In some cases, consumer direct shipments are made. A shipping leadtime of 2 days is practiced.

When the MP is considered, the orders are either make-to-order or replenishments based on sales data. Company uses an average bundle size of 24 pieces for the PBS and maintains an efficiency of 100%. About 100 different fabrics are used at a given time. Multi markers are used with about 3 days of order to marker leadtime. Numeric Control high ply cutters are used to cut fabrics and maintains a marker to finish cutting leadtime of 5 days.

According to the company executive, the following comments are important with respect to mass-customized apparel manufacturing.

- Single ply cutting capacity is important in MC.
- If MP and MC orders are mixed, one of the most difficult operations would be to track the orders. Delays due to bundle turnaround time will also affect the response time to the customer.
- If MP and MC orders are mixed, the major challenge is not to balance the bundle line but to overcome the cost issues as the bundle handling times are allocated in the SMV of the garment.
- When the cost for MC is considered the raw material cost and per-piece assembly and handling cost are increased.
- As the customer makes a deposit at the time of the order placement, MC orders have a better financial leverage over MP orders.

This company also practices Post Production Customization for small orders for which embroidered emblems are made. In addition, as required, the custom manufacturing unit (UPS) is also used for small MP order lots that need faster deliveries.

6.5 Personal Communication

The information provided below regarding apparel mass customization is based on the responses of the industry experts and consultants.

6.5.1 Interview 1

Profile of the interviewee: Industry consultant for build-to-order and mass customization, author of two books in Mass Customization, seminar and workshop organizer on build-to-order mass customization.

Even though the expert does not have specific experience related to apparel, the interviewee believes that the build-to-order mass-customization is a viable business model for the US apparel industry. The interviewee also believes in a business model which is neither extreme level of MP nor the extreme level of MC using the concept of fairly standardized input but obtaining a variety output with a critical mass of manufacturing. In identifying the lucrative nature of the business model, cost needs to be analyzed in total rather than in partial such as labor cost which mislead the decisions such as out sourcing. The appropriation of overheads must also be carefully carried out for individual product lines first and then as a whole for the full organization.

The interviewee believes that the technology is in place but need to be organized for the MC business model. A similar but more organized and developed supply chain management system is required for the mixed MP, MC manufacturing business model. The raw material supply side needs to be more organized with some standardization of raw materials for the build-to-order MC business. The order entry and re-order systems must be organized. Using these available but better organized techniques the historical EOQ (may be about 1000 garments in apparel) needs to be brought down to a batch size of one or a smaller lot amount.

A closer look can be made to industries similar to apparel such as food, in identifying similar business models that can be used as a role model in developing this lucrative business model.

In terms of order tracking, the difference in MC is that individual units need to be tracked instead of batches as in MP. The technologies such as RFID are developing rapidly as not only apparel but other industries are moving in to manufacturing of small batches. One problem could be the cost of the technology as not only individual units but individual parts may need to be tracked in terms of apparel manufacturing where, for example, for a pair of blue jeans there can be as many as 28 pieces assembling together to obtain the final product.

The speaker believes that both MP and MC must be able to do in the same line except extreme level of MP to obtain extreme economies of scale and extreme level of MC to include high level of variety. Limiting the variety such as limiting the number of fabric types offered or standardizing the fabric (say, only Denim) may help in the ability to realize the business model. At the point of combining these ends one can find the critical mass that needs to be manufactured using the available organized technology. The repairs and returns can be reduced, in fact, through higher level of customization as the customer is delivered a product that is made for customer expectation.

The expert also believes that there has been a lot of "futuristic" speculation that the MC of clothes would involve body scanning as the order-fulfillment input to flexible apparel factories. Although this may enhance the mass customization of clothing in the future, most of the initial opportunities will be in simply combining many standard options (collars, tapers, pockets, belt loops, etc.) with a few dimensions which could even be in check-the-box increments to match today's sizes. This would be easy for customers to order over the phone, in catalog forms, on the internet, or in stores. Further, it would be easy to input to the factory without a lot of extra IT expenses and the infrastructure costs for scanning equipment and facilities. Besides, many people may resist body scanning for the reasons expressed, unfortunately, in a Wall Street Journal a year or two ago by Rebecca Quick, who publicly expressed her personal anxieties about the whole experience. This type of operation would be in that blurred area between build-to-order and mass customization. It could be marketed as mass-customization, but it would really be combining many features and options that are put together on-demand (build-to-order) along with a few cuts to-size (what he calls as dimensional customization). This would also be a good match with spontaneous on-demand build-to-order replenishment of standard sizes on the same lines.

6.5.2 Interview II

Profile of the interviewee: President of a corporation who has many years of experience in apparel operations and R & D. who has authored number of publications related to apparel mass customization and speaks about MC internationally.

In apparel MC it is important to know whether the product is for the ultimate consumer or for a customer. MC practice can apply to both. The retailer who has studied the sales information and place an order (build-to-order) to offer variety to the market also carryout MC in some sort. When it comes to personalization level, i.e. if the product is made based on consumer's requirement, it is the ultimate of MC. Therefore, MC lies in the range of variety offer and personalization. MC can be considered as subject of agile manufacturing.

Three vital factors for the success of MC can be suggested.

- Information Technology to capture information at the point of purchase and the ability to direct it to the appropriate process
- Re-configurable automation such as CNC cutting, digital printing. This is the ability to switch to different orders.
- Flexible manufacturing process, whatever one wants to name it, QR or Agile, etc.

The Points and Extent of Customization defined in this research is excellent. However, it is required to define the customer as discussed above. This is because, for example, in Fabrication Customization, digital printing can be used for a personalized build-to-order, which is different from a retailer specifying number of fabrics to offer variety. The spectrum of MC is much larger. The Points defined in this research are mostly aiming at a consumer end. For example, for Fit customization, it is required to have the end consumer in the supply chain. Based on the customer, the following analysis (Table 6.18) can be made to decide whether the author defined Points of Customization can be used in apparel MC.

Table 6.18: Point of Customization and end customer

Point of Customization	MC: For the end Consumer	MC: Not for the end consumer
Design	Yes	No
Fit	Yes	Yes to some extent ex: tight fit, loose fit,
Fabrication	Yes, using digital printing	Yes, Offering wide variety of fabrics
Feature	Yes	Yes, offering variety of features
Post Production	Yes	Yes

It is the ability of a company that defines the combinations of the above that can be offered to the customer. It is very important to understand how these combinations can be configured in the manufacturing. Seamless integration of technologies provides the ability for mass customization. Currently we are ready to practice MC with right technologies in place. Order tracking is an important aspect and with barcode, RFID, and internet, we will have technology to track individual pieces even in production.

The interviewee has not come across mixed manufacturing of apparel in the same production units but in different units. Mixing of MP, MC may depend on the degree of customization. However, with the improvement of logistics, etc. MC could even be achieved with outsourcing (for example, a delivery leadtimes of 2 weeks from Guatemala).

Technologies such as the wholegarment knitting might revolutionize the MC process in the future. Currently, the wholegarment MP is practiced and even though this technology is not ready to achieve the flexibility to queue different garments required by MC, it will realize in the future. This technology will overcome the problems of processing different styles or categories such as sewing pants followed by shirts, etc.

which is impossible in the today's assembly systems. Further, technologies such as digital printing will overcome the costs such as cost of stocking fabric for MC.

6.5.3 Interview III

Profile of the interviewees: Two experts were interviewed from a corporation specializing in consultancy and R&D for the apparel industry in the U.S. The two interviewees hold the positions as industry director for supply chain analysis and corporate vice president for research who have experience and knowledge in apparel MC.

When the extent of customization is considered, once the choices that are offered to the customer gets wider, the extent gets closer to design customization. This is more towards tailoring and there are companies who have this as their business model. Over the time it was seen that companies who practiced this type of pure customization were not successful. Also, it is always better to limit the choice for the customer as the customer does not have sufficient knowledge to make a decision in terms of fabric type, comfortability, performance etc. This also helps the business to reduce the complexity of the total supply chain of a particular line of product in achieving MC.

In addition to the author suggested methods to obtain fit in the research[1], interviewees proposed the following methods.

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[1] See Appendix C1: Survey Instrument

- Sending measuring teams to the customers (specially in the uniform business the company sends a team of people to the firms that buy corporate apparel)
- Wardrobe customization (This business model contains maintaining a personal wardrobe for a season or year around) by clothing consultants.
- Direct sales staff to obtain the fit measurements.

When the available technologies are considered, there are technologies which are advanced enough to carryout the business of apparel mass customization. Three weeks leadtime that can be seen with some companies is important and in some cases the profit margin is sufficient to manufacture the garment overseas and send to the customer by air. It is an important role to obtain customer requirements for MC and Internet websites, catalog sales, direct sales staff, and clothing consultants may be able to interact with the consumer to obtain information (elicitation) for MC.

Some companies manufacture both MP and MC in the same production line, where as others manufacture in separate sewing units. One of the manufacturing limitations is that changing thread colors in the apparel assembly process when practice MC. As most who try to practice 100% custom clothing have failed, it is suggested that it is safer to have mixed MP and MC. The belief is that it is always easy to manufacture MP orders in a customized product line than vice versa.

When customizing fit is considered, ability to make new patterns automatically and use existing patterns and modify (blue penciling) are ways to alter patterns for fit customization. New developments are on the way to open the body-scanned image in to patterns. Tracking a single unit instead of a batch (as previously done) is a big task and an expensive process. The RFID systems are expensive and not seen much in US apparel manufacturing sector.

When the cost of MC is considered, per piece assembly cost and order handling cost could be higher. The finish goods inventory cost will be low as the garments will be sent to the customer. Raw material inventory cost can be higher or lower depending on the variety of raw material that is being offered to the customer.

6.6 DISCUSSION

Based on the analyzed results, the following decisions are made regarding the research hypotheses.

H1: “MP and MC mixed manufacturing of apparel can be done in the same production unit” is accepted based on the following reasons.

- Simulation results suggest that the PBS can be used for Mixed MP and MC manufacturing in the same production line. However, based on the MC volume, limitations exist. It should also be noted that the simulation used only Feature Point of Customization with a very low Extent of Customization (monogramming).
- The Survey analysis provides further evidence to accept this hypothesis by providing industry practice information on mixed MP and MC manufacturing in the same line. As per the results 32% of the companies use same production system for MP and MC.

- Information gathered from the Case Study and Personal Communication methods, further agree to H1. However, other supporting technologies must be in place to achieve success e.g. RFID for order/part tracking.

H2: “Technological advancements in apparel assembly and innovations in supporting technologies have taken place which support MC apparel manufacturing”

- Based on the critical literature review in the research, the author agreed to the above hypothesis. This statement is further supported by the response information from the industry experts that was obtained from personal communication. For example the Internet which actually came in to power during 1990’s provided a greater assistance for apparel MC.

H3: The MP is becoming custom production. In other words as the number of MC orders grow bigger it is suitable to have a dedicated manufacturing system for the customized manufacturing.

H3 is accepted due to the following reasons.

- Literature provides information of firms from other industries that have moved to dedicated MC production units with the increase in MC volumes.
- The results from PBS simulation of mixed manufacturing suggest that, as the MC volume increases it is sensible to use large bundle sizes. However, as the bundle size increases, the TPT need to be considered. Also, after a certain limit of MC volume, the system performance drops rapidly.

- The firm which participated in the Case Study use a dedicated line for MC when there is sufficient MC orders. This production system is also used for MP of small lots.

H4: The ability to efficiently mix MP and MC in the manufacturing will depend on the extent of customization that depends on the points of customization.

- This hypothesis is true as indicated by the industry practice information discussed under the “Points and Extents of Mass Customization Practice” in the survey analysis. Higher percentage of firms use Post Production Customization which has the least affect for the manufacturing process while lowest percentage of companies use Design customization that has the most effect on manufacturing. The industry experts also agree to this hypothesis.

H5: The MC continuum is not a linear model

- The author’s analysis based on the model proposed by Anderson et al (1995) shows that the MC continuum is not linear. However, this was not the main focus of this research and could be a subject for further research.

H6: For operations aspect the order tracking system should be technologically advanced in the mixed manufacturing model.

- According to the information analyzed from Case Study and Personal Communication, order tracking is an important element in the mixed MP and MC manufacturing. The technologies such as RFID is expected to play a major role in this aspect.

H7: Benchmarking product development from concept to manufacturing apparel is important to identify the existing practice of MP and MC

- The literature addressed the benchmarking parameters for apparel manufacturing.

The survey analysis discusses such measures that is practiced by firms which practice apparel MP and MC.

CHAPTER 7

7 SUMMARY AND CONCLUSIONS

Enterprises in all branches of industry are becoming more customer centric. The increasing interest and effort of business practices heading towards mass customization demands intensified study of this approach from research and academia. Though the concept of MC was coined in the mid 1980's, sufficient research has not started to pickup until recent years. The objective of this research was not only to research the state of the art of methods, approaches, obstacles and challenges for MC but also to analyze the proposed concept of mixed MP and MC apparel manufacturing with its current practice, potential and capabilities.

With the increased consumer power in making purchasing decisions based on the satisfaction of consuming the apparel product, customizing apparel products to the needs of the consumer is inevitable. Custom apparel production is not a new concept but has been in practice for centuries with manufacturing systems such as Make Through. However, the cost of these custom produced goods was high and unable to compete with the low cost mass produced apparel. Therefore, companies have started to exploit their competitive advantage by using the comparative advantage of using MC business model to produce goods at a competitive price with mass produced apparel. The discussion of finding the possibility of mixed MP and MC led the research.

This research has made significant contribution to the knowledge base in literature, methodology, theory and practice of mixed MP/MC apparel manufacturing. A comprehensive analysis of available literature for apparel MP, manufacturing systems, technology infrastructure, principles, techniques and cost economics of apparel MC, and benchmarks for new products was made. Methodological contributions provide strategies to test the hypotheses and assessing the validity of proposed original concepts. Results from simulation modeling, industry survey, case study and personal communication were used to analyze both the theoretical and practical perspectives of the research.

7.1 CONTRIBUTION TO LITERATURE

A detail analysis of existing MP apparel manufacturing systems leads to the development of a comprehensive attribute comparison table that can be used to define the manufacturing systems. This summarized information model was extensively used in manufacturing system modeling for the simulation approach. The discussion of FMS, assembly technology, and supporting technology infrastructure provided an in depth knowledge on how well the existing systems can support the research objectives. Compiling the literature on apparel MC under one umbrella with number of perspectives such as cost economics of MC, principles and techniques for MC, and the design, ordering and execution process for MC assisted in designing the methodologies to achieve the research objectives. The benchmarking parameters further assisted in analyzing the results appropriately.

7.2 CONTRIBUTION TO METHODOLOGY

In the context of the current research, a methodology was designed for synthesizing results of multiple research studies and validating the combined results with the industry practice information. This multiple method approach was developed with the expectation of testing the hypotheses that were developed to achieve the research objectives. The manufacturing system modeling and simulation method provided the quantitative investigation of mixing MP and MC in different production systems. The models were developed based on the information obtained from the industry that practice mixed MP and MC apparel manufacturing. The survey instruments assisted to collect industry practice information for results validation. A case study and personal communication instruments further assisted in obtaining information regarding industry practice and future expectations. In addition, these instruments gathered information that can be used as benchmarks for the firms that are interested in implementing a MC business model. It is also expected that this information will help future academic and industry research.

7.3 CONTRIBUTION TO THEORY AND PRACTICE

Research hypotheses proposed number of original concepts for the current research. Mixed manufacturing of MP and MC in the same production line and the Points of Customization [DCP, FBCP, FTCP, FRCP and PPCP] are emphasized. The technology readiness for apparel mass customization is questioned. With the increasing demand for customized apparel, MP may become custom production with dedicated production lines. Some of these concepts need to be further researched that will benefit the apparel industry.

7.4 CONTRIBUTION TO THE APPAREL INDUSTRY

The simulation method of the current research addressed the scenarios of mixing MP and MC apparel in PBS and Kanban production systems. The results proposed number of recommendations based on the manufacturing system, bundle size, etc. that one can practice mixed MP/MC in the existing same production line. For example, a company that currently uses a PBS for MP apparel manufacturing may use the line for MC apparel with some limitations based on the bundle size provided that suitable technology is in place to overcome other difficulties such as part/order tracking. Information obtained for current industry practices of apparel MC can be used as benchmarks for firms that have plans for MC business models. The literature that addresses the economics of MC proposes that, companies that practice MC have a comparative advantage over the MP companies when the markdowns, stock-outs, etc. are considered.

7.5 CONCLUSION

Mass Customization is growing in importance. Research and development for technological advancements that support MC is on its way. Academic research and development of the theoretical and managerial aspects of MC is increasing. Books with the subject of MC are written and published. Since 1989 more than 2700 articles in English on MC have been published, out of which 60% were within the last 3 years (Tseng & Pillar, 2003). More companies are moving into the practice of MC business models.

The economic advantage of MC has become the driving factor in a successful MC business. The business analysis by KSA shows the cost benefits from MC that can be enjoyed by the manufacturers, retailers and consumers. Based on the KSA analysis, the manufacturing cost of a basic MC apparel product is about 34% higher compared to the standard product. However, avoiding markdowns, charge-backs, etc. generate better financial gains. Establishing FMS to cater for the changing market place will provide the continuing ability to gain competitive advantage.

As the authors suggest, it is the appropriate time to develop a simulation model for MC that address the full model of design, order and execution. The customer who needs a customized apparel product must have the ability to simulate the design, order and through the execution stage, to obtain information about the purchasing decision.

Most apparel companies practice MP and as they move into the business of MC they are required to identify a suitable manufacturing strategy. The question is whether the MC products can be manufactured in the MP systems or if is it required to have separate production units for MC. The extent to which MC product can be manufactured in the MP systems is another question. This research was developed to investigate these questions. Based on the results, it was found that mixed MP and MC is possible in the same production unit but limited by the volume of MC products. However, this possibility also depends on the Point of Customization and the Extent of Customization which were addressed in the research. It was also found hat there are companies which practice MP and MC in the same production unit as well as in separate production units. In addition, wide veariety of industry practice information was found that can be used as measures in MC.

7.6 RECOMMENDATIONS FOR FUTURE RESEARCH

- MC Continuum

As discussed in Chapter 6, Survey Analysis section, the MC continuum is a complex model. To understand MC continuum among the Points of Customization, each Point needs to be separately addressed and all the Points need to be collectively considered. If the MC continuum can be defined, manufacturing approaches for the levels can be understood.

- Simulation of UPS

Due to modeling constraints, the TC2TeamMate® simulation tool could not be used to simulate a UPS which was the primary objective in "integrating MP into the MC production line" to observe the system behavior. Simulating a UPS is proposed to investigate the performance of mixing MC and MP in a MC UPS line.

- Simulation improvement

Due to limitations in the simulation tool, alternating MP-MC style arrival was simulated. As this is an extreme level of mixing, a random order arrival needs to be analyzed. The simulation tool needs to be modified for random order arrival as the available options were "one time", alternating "periodic" or "evenly spaced" orders.

- Case Studies

Based on the response of the Survey Instrument, three more companies showed interests in participating to develop Case Studies. This is a good opportunity to further evaluate the industry practice of apparel MC.

- A complete simulation model for apparel MC

A simulation model for MC that addresses the full process of design, order and execution is demanded. The customer who needs a customized apparel product must have the ability to simulate the design, order and through the execution stage and obtain information about the purchasing decision.

When the cost effects of customization are considered, it should be taken into account that customization seems to be a dominant paradigm in the apparel industry. Therefore, the most important issue is not necessarily the comparison of costs of standardization and the cost of customization. Rather, it would be more beneficial to assess and compare the costs of different means of accomplishing customization. Efficient management of customization might be an important competitive factor in the future. In other words, the question is not whether to customize or not to customize, the question is how to customize.

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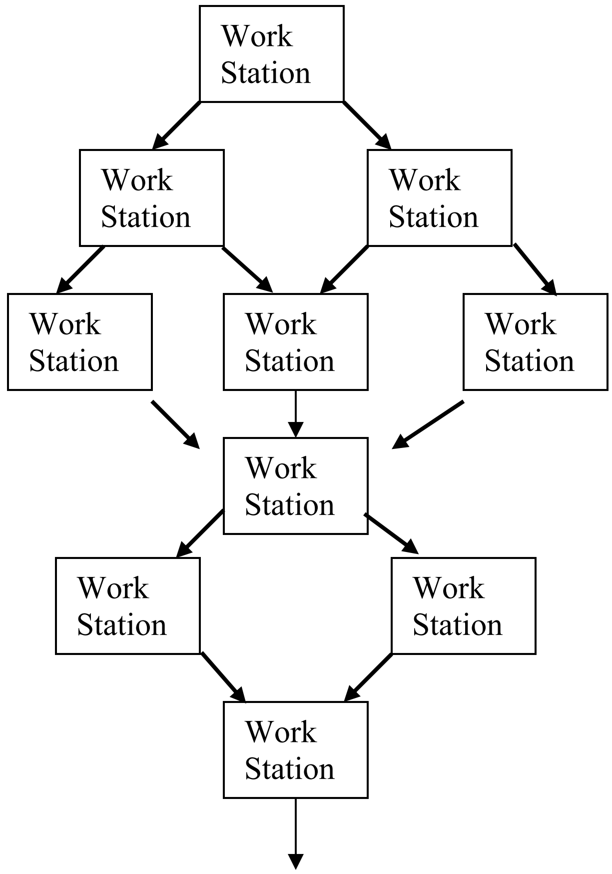
9 APPENDICES

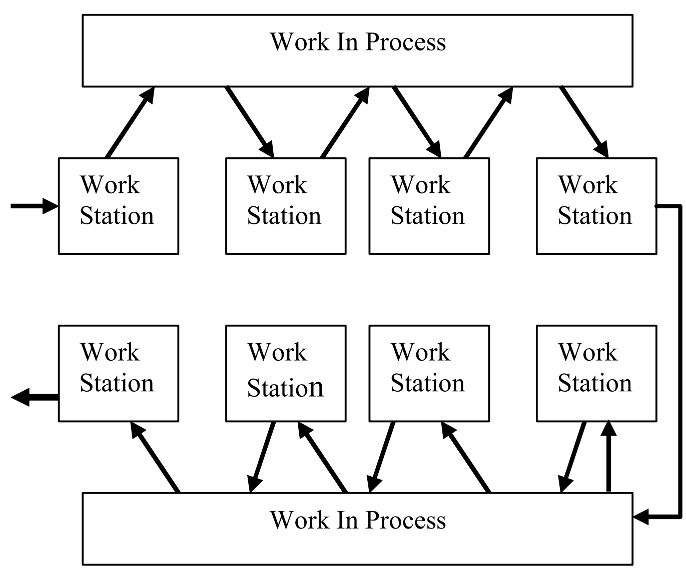
APPENDIX A

MANUFACTURING SYSTEM LAYOUTS (AAMA, 1988).

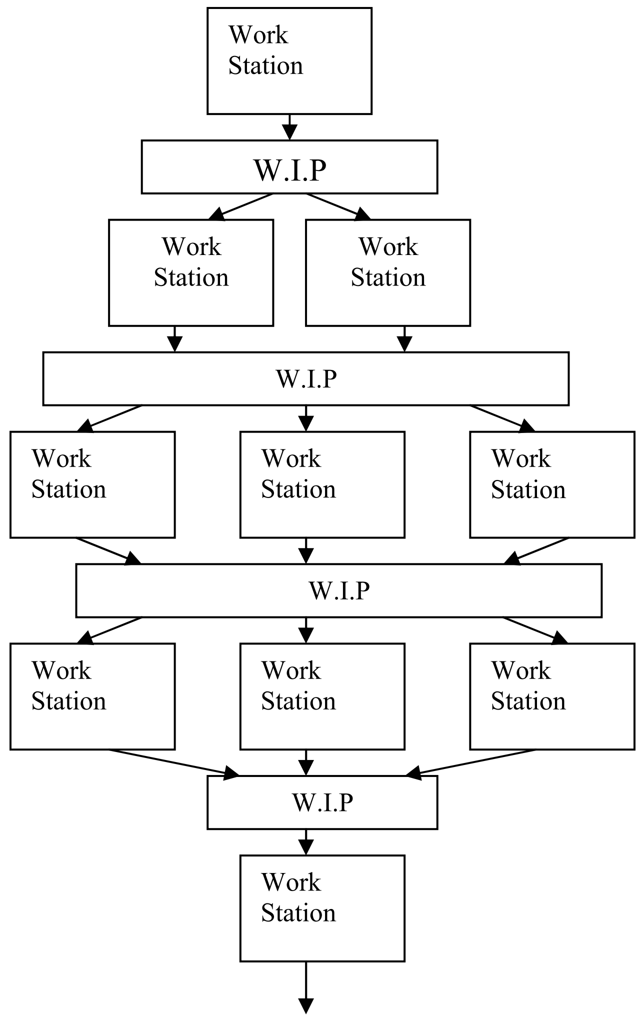
Line:



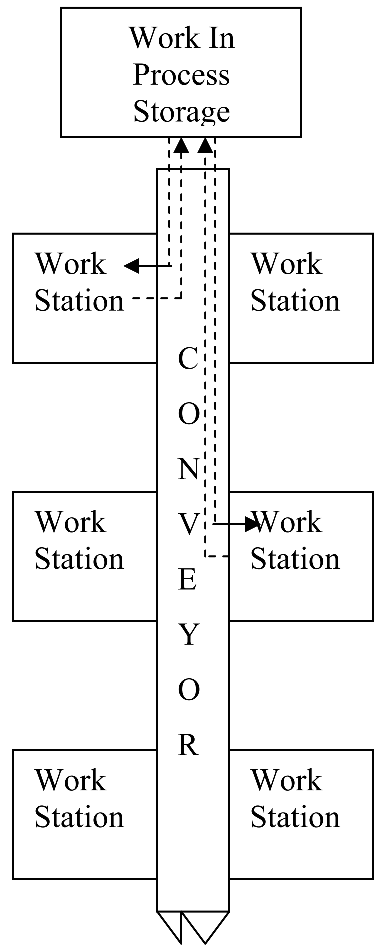
Straight Bundle:



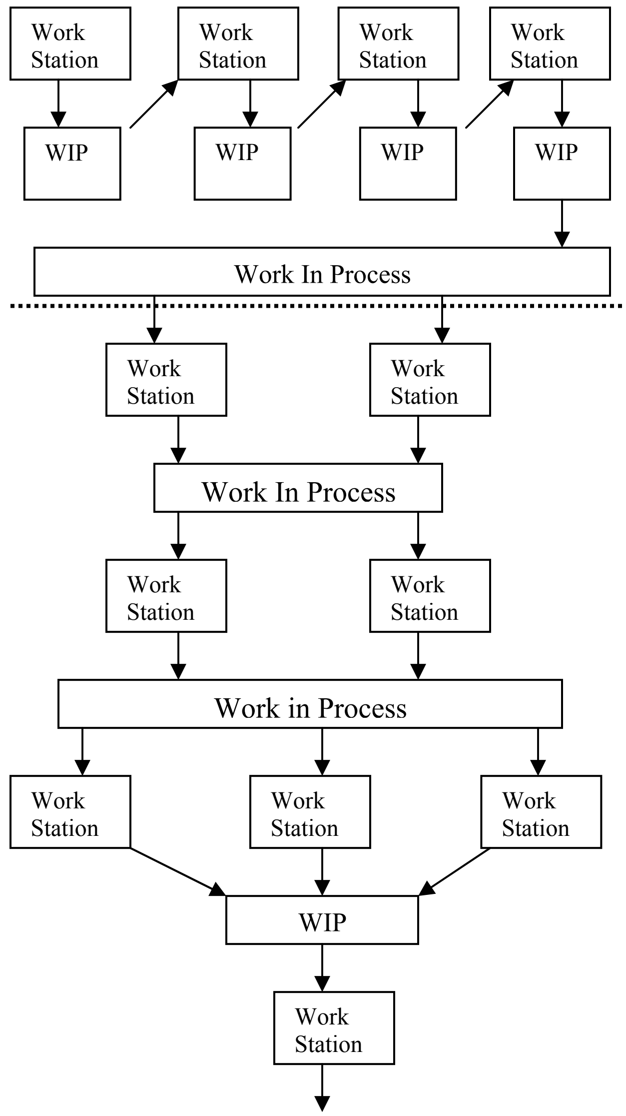
Progressive Bundle:



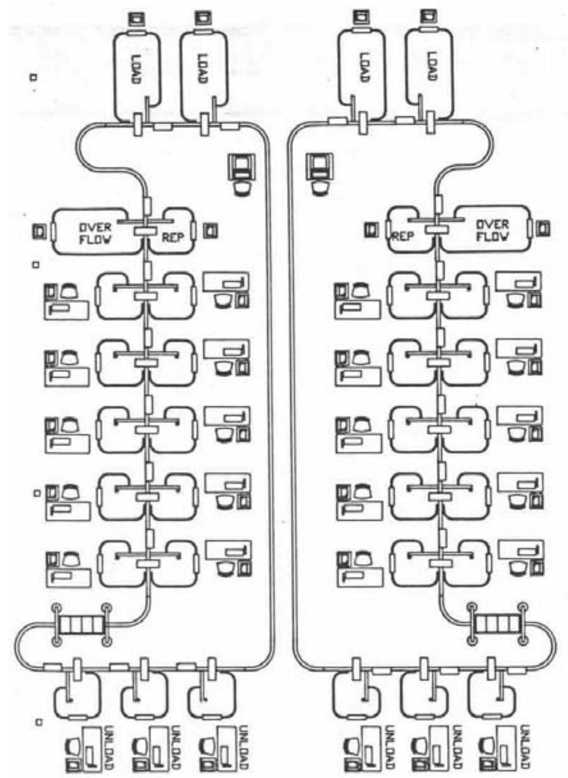
Transporter:



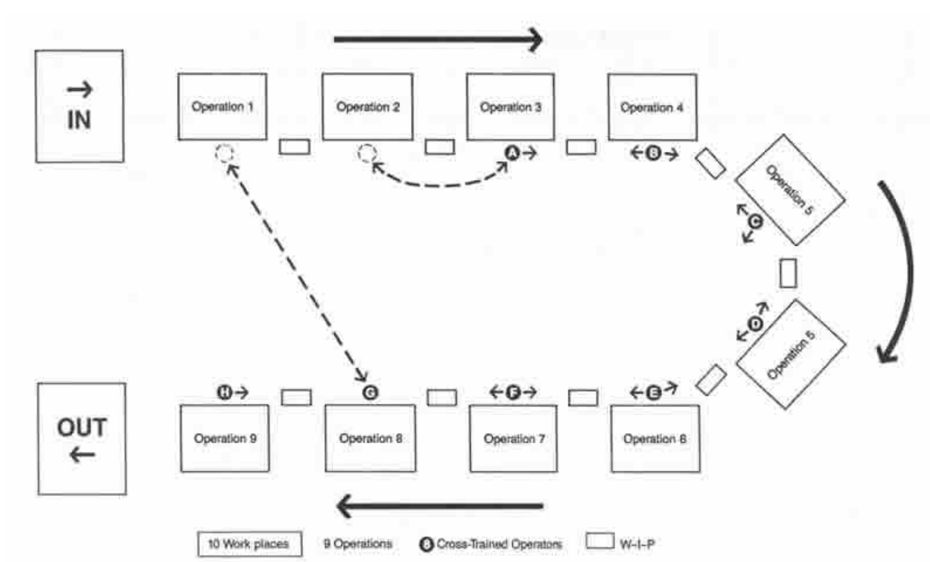
Progressive Bundle with Skill Center:



Unit Production System:



Modular Manufacturing System:



APPENDIX B

SIMULATION TOOL

$[TC]^2$ TeamMate® Apparel Production Simulation Tool

The $[TC]^2$ TeamMate is a production simulation tool which provides the user to run various scenarios before actual production begins to identify bottle necks. The front end of the tool is a set of Access Data Base forms linked by Visual Basic coding and the back end is an ARENA simulation model which has its source code written in SIMAN Simulation language. The $[TC]^2$ TeamMate Series contains a set of engineering and planning tools that can be applied to a range of manufacturing systems. The production is defined based on the station type which can be "hand-off", "kanban", "hand-off/kanban" or "progressive bundle". Included are special features for team-based systems, characterized by flexibility and continuous change. The foundation of the series is a database application with rough-cut capacity planning features. It replaces the paper system with a centralized database, checks the machine capacity, assists in operator task assignments, and generates presentation-quality reports. It stores operator skill history so it can be used to determine which operators have the desired skills when setting up a manufacturing line for a new product.

Building on the database, there is a dynamic analysis level. This level provides the capability to determine the productivity of different alternatives as new production lines are designed. It allows to compare stand-up, hand-off teams to sit down teams, to add kanbans to different operations, to link a feeder line that runs batches to a hand-off team, etc. This tool is helpful when it comes to setting up new styles and determining production goals that account for varying efficiencies and operator movement within the confined boundaries of production systems. As in any other menu driven program, new scenarios can be created saved and recalled.

The system information defines the data that is system wide in nature. General categories are default efficiencies, system controls, machine breakdowns, system variability and bundle handling. The system settings provide miscellaneous, global parameters for a specific scenario such as operator settings (default efficiency, cost calculation efficiency, operator/handler walking speed and operator movement control batch limits), system settings (operation times and date, simulation time, machine breakdown times, allowed variances on parameters) and WIP units for bundle handling and default station distances.

A station is defined in the simulation tool as a group of machines, physically located together that perform the same set of operations. Each machine within the station is operated independently to perform any operation required by an end item or sub assembly at the station. Single or multiple stations can be added, deleted or edited. The station menu provides the input fields for station definition which consists of station number, name, type, WIP levels, number of machines and types, machine repair times, time between machine failures and batches re-directing methods. The WIP levels provide the ability of WIP inventory control as well as operator movement controls.

Production line is defined in the tool as a group of machines that form a module or work cell. A team of operators is assigned to each production line. 'Production line definition' window provides the user to enter the production line information such as name, number of handlers and handler walking speed. It also enables to create a distance matrix for station placement so that work-moving speed can be incorporated. WIP controls that are entered in the production line can be set to enforce and over write the individual station WIP. The line WIP can be set to control maximum batches per line. Production line type will be based on the station types defined. Also, for financial requirements the operator base pay rate for the entire line can be defined which can be changed with the operation definition.

The style menu provides the styles to be added, deleted, edited or copied. In the tool, style is a unique product having a process plan which defines the sequence of operations required to transform raw materials to finished goods or finished components. The process plan designates which station is to be used to perform each operation and the associated time requirement. It also specifies the type of operation and all material quantities required, for example sub assemblies. A unique style name can be entered with a product type as an “end item” or “subassembly”. Upon entering the operation sequence with the standard allowed time for each operation, the total standard allowed minutes for the style is displayed. For sub assembly styles, start time allowance can be allocated as a buffer to the start of the components before an end item is started. The system allows entering material cost and selling price for financial calculations. The inspection method can be selected. An icon can be selected which will be used for the simulation animation. Moving in to the next level of the style operations, operation name, operation type, skill group, operation station, and processing time can be defined. Further, the inspection time, rework time, defect percentage and operator base pay rate can be entered in relation to the particular operation. For an assembly operation, the subassembly parts and the part quantities can be selected. Additional set up times for the respective operations can be defined.

The cut pieces from which finished goods are produced can be arrived to the production system at various times defined by orders and their arrival pattern. The menus, which handle data related to orders, provide adding, deleting and editing orders. Style name and production line for the order is selected and the order information such as order quantity, batch quantity, start time and date, due date and order priority can be specified. Three options for order arrival is available; “one time”, “evenly spread” and “periodic orders”. The orders may need bundle integrity to be maintained (if subassembly is used) and components to be synchronized (for end items to have appropriate subassemblies on time) that are available options. User defined attributes can be defined for the order styles that may need to track the orders. The color for an order can be defined if one is interested in tracking color for set up or ranking purposes.

The starting WIP menu option provides the production line to have a starting buffer stock before the actual orders begin manufacturing and at the start of the simulation. WIP can be added across or to individual operations or operators. The WIP can be added, edited or deleted based on the style, quantity, and station.

The operator menu option defines operators who are trained to perform a set of operations that fall in to categories called skill groups. The operation is performed in a skill group at a given level efficiency that needs to be specified. Multiple or individual operators can be added or deleted. Individual operators can be edited or copied. The operator’s initial location in the production line, pay premium, and movement decision can be defined. Multiple skills and their efficiencies can be added for each operator with the update date of individual skills. This provides a skill inventory database for the manufacturing environment. The skill group must always match the one entered at the operations stage of the style definition.

The movement rules menu option defines the logic that operator would think through to select a single station as an option to move to based on current system conditions. This is in the case of team sewing environments and not with progressive bundle system type stations. New rules can be added or existing rules can be altered, modified or deleted. A movement decision describes the decision process an operator will follow when deciding his/her next action. This decision involves evaluating a series of prioritized movement rules; each would give the operator one choice of a station to move.

This tool also comprises of additional features. A 'run data check' option is available to check the feasibility of the production scenario before the simulation. A capacity check menu option is available which will display a station utilization based on the projected machine utilization at each station based on the information entered. This provides an easy visualization of capacity balance at each workstation. An operator assignment menu option is available which can be used to group operations in to zones that can be balanced with the given number of operators. This provides the information of number of sequential operations each operator has to perform for team sewing environment. Simulation can be run with or without animation. The reports menu provides the user to obtain summaries of all of the input data reports and results reports from the most recently completed simulation scenario. Some of the out put reports consist of;

- System summary – includes high level of production summary, operator and station utilization summaries and system WIP summary

- Production summary by style – includes ordered and completed amounts and cycle times
- Operator utilization by skill and activity – includes the percent of time each operator spent at each skill and contribution towards value added or non value added productivity
- Station performance – includes WIP data and utilization information
- Financial summaries – includes standard costs of operator and production lines

Assumptions of the simulation tool are discussed in the operator manual in detail.

APPENDIX C

MIXED MP/MC INDUSTRY SURVEY

APPENDIX C1: SURVEY INSTRUMENT

Survey of Current Mass Customization Practices

College of Textiles, North Carolina State University is conducting this survey to obtain qualitative and quantitative information on mixed mass-customized apparel manufacturing.

Thank you for the information you provide which will help us to model the practice of mixed manufacturing for mass-customized apparel. The survey is being sent to 20 carefully selected companies engaged in apparel Mass Customization; therefore your input is most valuable. Your response will be held confidential and we greatly appreciate your participation.

A copy of the compiled results of this survey will be sent to participants.

Should you have any question or difficulty in responding please e-mail us at:mmsenana@unity.ncsu.edu or call (919) 515 6620.

Color Coded Route:

: Section A & B – Extent of Customization & Leadtime Practice

: Section C – Manufacturing Practice

: Mixed Manufacturing

: Mass Production - MP

: Mass-customized Production – MC

: Section D & E – Business Practice (Shipping and Costs)

: Section F - Additional questions (Company Profile, Future Contacting)

Section A:

Extent of Customization Practice

Apparel categories

What categories of apparel do you manufacture? (Ex: men's shirts, women's jeans, swimwear etc.) ____

1. Design Customization (customer has the ability to **design/develop** the garment with no restriction)

Do you allow the customer to fully design the garment?

(Survey considers this as an extreme level of customization that allows the customer to design the entire style of garment within your product category)

1. Yes ☐ No ☐

2. If yes, please explain the process

____

2. Fabrication Customization (provides customer with the option to decide on the material within your product category)
What "fabrication customization" you offer? (Please select all that apply).

☐ Any **fabric**, no restriction

☐ Company provided fabric **Types** (woven, knit, rib)

☐ Company provided fabric **Prints/Designs**

☐ Company provided fabric **Colors**

☐ **Other** company provided **Fabric Characteristics** Please name ______________________________

☐ Any **Accessory**, No restriction

☐ Company provided **Accessories** and **trims** Please name ______________________________

3. Feature Customization (provides customer with the option to decide on **features** to be included during manufacturing within your product category)
What "feature customization" you offer (Please select all that apply).

Company provided	Customer specified
☐ Construction features (ex # of loops/pockets, cuff shape, darts etc.) Please name ______________________	☐ Monograms at ☐ Company provided placement ☐ Customer specified placement
☐ Emblems, logos, prints, photos at ☐ Company provided placement ☐ Customer specified placement	☐ Emblems, logos, prints, photos at ☐ Company provided placement ☐ Customer specified placement
☐ Ornamental stitching features (ex: top stitching) Please name ______________________	☐ Other Please name ______________________
☐ Washing/Finishing (ex: stain resistant) Please name ______________________	
☐ Other Please name ______________________	

4. Fit Customization (provides customer with the option to decide on **fit** within your product category)
Do you customize **fit** by (Please select all that apply)

☐ Body scanning by company

☐ Copying from customer provided garment

☐ Measurements taken at location (store)

☐ Customer obtained measurements

☐ Adjustments by try-on existing size

☐ General fit description (ex: relaxed fit, boot cut) Please name ______________________

☐ Other, please name ______________________

5. Post Production Customization

1. Do you offer customization from mass produced stocks (ex: monogram, print logo, embroidered emblems on already mass produced stocks)

☐Yes ☐ No

If yes, please explain what is customized ____

If yes, please explain where customization takes place (ex: at the warehouse, at the distribution center) ____

2. Do you offer customized packing (ex: boxed, bagged, hangers, folded, pinned, etc.)?

☐ Yes ☐ No

If yes, please explain____

Section B

Customization Lead-time Practice

Lead time for Customization

Please specify the **lead time you offer to customers** for customization combinations available in your business.

Customization	Lead time
☐ Design customization only	____ Days
☐ Fabrication customization only	____ Days
☐ Feature customization only	____ Days
☐ Fit customization only	____ Days
☐ Fabrication & Feature	____ Days
☐ Fabrication & Fit	____ Days
☐ Fit and Feature	____ Days
☐ Fabrication, Feature and Fit	____ Days
☐ Post production–customized from stock	____ Days
☐ Full custom (Not Mass Custom)	____ Days
☐ Other combinations: please name __________________ ___________________	____ Days ____ Days

Section C Mass Customization Manufacturing Practice

Note: MP - Mass Production
MC - Mass-customized Production

Please select your apparel manufacturing practice from the 4 options below.

1. ☐ **Mixed Production – MP & MC in the same sewing production line**
2. ☐ **Mixed Production – MP & MC in separate sewing production lines**
3. ☐ **Mass Production and then Customize (Post-Production Customization-ex: embroidery)**
4. ☐ **Mass-customized production only**

If your answer was 1 above go to section C.1 below
If your answer was 2 above go to section C.2 and then C.3 below
If your answer was 3 above go to section C.2 below
If your answer was 4 above go to section C.3 below

Section C.1 Mixed MP and MC practice

1. Does your **MC** change garment Patterns? ☐ Yes ☐ No
If Yes, Do you

	Leadtime (*Order to Pattern ready*)
☐ Make new patterns	____Days ____ Hours
☐ Use existing patterns and modify	____Days ____ Hours

2. Type of **Markers** use and the **leadtime** for **MP** and **MC** orders (*from order to marker ready*)

Marker Type	MP Leadtime	MC Leadtime
☐ Multi marker	____Days ____ Hours	____Days ____ Hours
☐ Single marker	____Days ____ Hours	____Days ____ Hours

3.Cutting **methods/equipment** use and average **lead- time** *(from marker ready to finish cutting).*
(Ex: manual, die cutting, NC high/low/single ply, laser, ultrasonic, shears, water-jet, other)

	Multi-ply cutting method	Lead -time	Single-ply cutting method	Leadtime
MP	1. ______	____Days ____ Hours	1. ______	____Days ____ Hours
	2. ______	____Days ____ Hours	2. ______	____Days ____ Hours
	3. ______	____Days ____ Hours	3. ______	____Days ____ Hours
MC	1. ______	____Days ____ Hours	1. ______	____Days ____ Hours
	2. ______	____Days ____ Hours	2. ______	____Days ____ Hours
	3. ______	____Days ____ Hours	3. ______	____Days ____ Hours

4. Your **Mixed Production** System and **efficiency**:

System	Efficiency (%)	System	Efficiency (%)
☐ Line	_____	☐ Modular/seated	_____
☐ Bundle system	_____	☐ Modular/stand up	_____
☐ UPS	_____	☐ Other, Please name: _______________	_____

5. What is the **production unit** moving in the line?

	A single garment	A bundle	Bundle size
MP	☐	☐	_____
MC	☐	☐	_____

6. **Mixed Production** done in **US** or **Overseas** (please name) and the **leadtime** *(Order to finish goods)*

	US	Overseas					
	Leadtime	Country 1	Leadtime	Country 2	Leadtime	Country 3	Leadtime
MP	____ Months ____ Days	_____	____ Months ____ Days	_____	____ Months ____ Days	_____	____ Months ____ Days
MC	____ Days	_____	____ Days	_____	____ Days	_____	____ Days

Section C.2 Mass Production (MP) practice

1. Type of **Markers** use and the **leadtime** *(from order to marker ready)*

Marker type	Leadtime
☐ Multi marker	_____Days _____ Hours
☐ Single marker	_____Days _____ Hours

2. Cutting **methods/equipment** use and average **leadtime** *(from marker ready to finish cutting).*
(Ex: manual, die cutting, NC high/low/single ply, laser, ultrasonic, water jet, shears, other)

	Multi-ply	Lead -time	Single-ply	Leadtime
MP	1. _____	_____Days _____ Hours	1. _____	_____Days _____ Hours
	2. _____	_____Days _____ Hours	2. _____	_____Days _____ Hours
	3. _____	_____Days _____ Hours	3. _____	_____Days _____ Hours

3. Do you base **MP** on?
☐ Forecasts ☐ Make-to-order ☐ Other, Please name ___________________________

4. Your **MP** System and **efficiency**:

System	Efficiency (%)	System	Efficiency (%)
☐ Line	_____	☐ Modular/Seated	_____
☐ Bundle system	_____	☐ Modular/Stand up	_____
☐ UPS	_____	☐ Other, Please name: _______________ ___________________________	___________ ___________

5. What is the **production unit** moving in the line?

	A single garment	A bundle	Bundle size
MP	☐	☐	_____

6. **MP** done in **US** or **Overseas** (please name) and the **leadtime** *(Order to finish goods)*

	US	Overseas					
	Leadtime	Country 1	Leadtime	Country 2	Leadtime	Country 3	Leadtime
MP	___ Months ___ Days	_____	___ Months ___ Days	_____	___ Months ___ Days	_____	___ Months ___ Days

7. If you practice **Post Production Customization** (ex: embroidery after MP), what is the
leadtime *from finish MP to finish Customization*? ____ Days ____ Hours

Section C.3 Mass-customized Production (MC) practice

1. Does your MC change garment Patterns? ☐ Yes ☐ No

If Yes, Do you

	Leadtime *(Order to Pattern ready)*
☐ Make new patterns	____ Days ____ Hours
☐ Use existing patterns and modify	____ Days ____ Hours

2. Type of **Markers** use and the **leadtime** *(from order to marker ready)*

Marker type	Leadtime
☐ Multi marker	____ Days ____ Hours
☐ Single marker	____ Days ____ Hours

3. Cutting **methods/equipment** use and average **leadtime** *(from marker ready to finish cutting).*
(Ex: manual, die cutting, NC high/low/single ply, laser, ultrasonic, water jet, shears, other)

	Multi-ply	Lead -time	Single-ply	Leadtime
MC	1. ______	____ Days ____ Hours	1. ______	____ Days ____ Hours
	2. ______	____ Days ____ Hours	2. ______	____ Days ____ Hours
	3. ______	____ Days ____ Hours	3. ______	____ Days ____ Hours

4. Do you base Mass-customized production on Make-to-Order?
☐ Yes ☐ No ☐ Other, Please name
____

5. Your **MC** System and **efficiency**:

System	Efficiency (%)	System	Efficiency (%)
☐ Line	______	☐ Modular/Seated	______
☐ Bundle system	______	☐ Modular/Stand up	______
☐ UPS	______	☐ Other, Please name: ______________	______

6. What is the **production unit** moving in the line?

	A single garment	A bundle	Bundle size
MC	☐	☐	______

7. **MC** done in **US** or **Overseas** (please name) and the **leadtime** *(Order to finish goods)*

	US	Overseas					
	Leadtime	Country 1	Leadtime	Country 2	Leadtime	Country 3	Leadtime
MC	_____ Days	______	_____ Days	______	_____ Days	______	_____ Days

Section D

Business Practice - Distribution

1. What is your **shipping practice** & **shipping leadtime** for **MP** orders (please include domestic production)?

Country of manufacture	Consumer Direct	To DC	DC to Store	Dc to Consumer	Store Direct
1	______ Months ______ Days	______ Months ______ Days	______ Months ______ Days	______ Months ______ Days	______ Months ______ Days
2	______ Months ______ Days	______ Months ______ Days	______ Months ______ Days	______ Months ______ Days	______ Months ______ Days
3	______ Months ______ Days	______ Months ______ Days	______ Months ______ Days	______ Months ______ Days	______ Months ______ Days

2. What is your **shipping practice** & **shipping leadtime** for **MC** orders (please include domestic production)?

Country of manufacture	Consumer Direct	To DC	DC to Store	Dc to Consumer	Store Direct
1	______ Days ______ Hours	______ Days ______ Hours	______ Days ______ Hours	______ Days ______ Hours	______ Days ______ Hours
2	______ Days ______ Hours	______ Days ______ Hours	______ Days ______ Hours	______ Days ______ Hours	______ Days ______ Hours
3	______ Days ______ Hours	______ Days ______ Hours	______ Days ______ Hours	______ Days ______ Hours	______ Days ______ Hours

Section E

Business Practice - Costs

1. Compared to MP of apparel, what can you say about the following costs for MC?

	Increased	Decreased	Not changed	Don't know	Not relevant
Per piece assembly cost	☐	☐	☐	☐	☐
Raw material cost	☐	☐	☐	☐	☐
Per piece order handling cost	☐	☐	☐	☐	☐

2. If you practice a combination of MP and MC what can you say about following costs?

Cost	Increased	Decreased	Not changed	Don't know	Not relevant
Marketing	☐	☐	☐	☐	☐
Sales	☐	☐	☐	☐	☐
Warehousing	☐	☐	☐	☐	☐
Distribution	☐	☐	☐	☐	☐
Product development	☐	☐	☐	☐	☐
Raw material inventory	☐	☐	☐	☐	☐
Work-in-process inventory	☐	☐	☐	☐	☐
Finished goods inventory cost	☐	☐	☐	☐	☐
As a whole total cost	☐	☐	☐	☐	☐

Section F

Additional questions

1. If you have any other method/system of apparel Mass Customization other than that is covered in this survey, please explain.

____

____

2. Would you be willing to assist in further developing a case study in mixed production (MP & MC) of apparel?

☐ Yes, Contact Iinformation____

☐ No

3. Are there other persons you might recommend that I should speak to regarding mixing Mass Production and Mass-customized apparel manufacturing?

Name____

Title____

Contact Information____

4. Company & User Profile

a. Company Name (optional) ____

b. Your Name (optional) _________________________ Title ____________________

c. Total Sales

	< 10M	10-50 M	50-100M	100-200M	200-500M	500-1B	>1B
MP	☐	☐	☐	☐	☐	☐	☐
MC	☐	☐	☐	☐	☐	☐	☐

APPENDIX C2: COVER LETTER

North Carolina State University is a land-
Grant university and a constituent institution
of The University of North Carolina

Department of Textile and Apparel Technology and Management
www.tx.ncsu.edu/tam/

NC STATE UNIVERSITY

College of Textiles
2401 Research Drive
Raleigh, NC 27695-8301

Date

Mr. *First Name Last Name*
Position
Company Name
Address

Dear *First Name*:

Your input in this study of Apparel Mass Customization Practices in USA will help formulate a vision for the US textile complex. This survey is a part of the Ph.D. dissertation research conducted by Muditha M. Senanayake under my supervision at North Carolina State University.

Modeling the manufacturing practice for customized apparel has been the research interest. Muditha has developed a mixed manufacturing model for Mass-customized apparel. The expert information you provide will be extremely valuable in validating the model and developing a more robust model which can be used by the US apparel industry to make strategic decisions in an era of Mass Customization.

We are contacting a selected sample of 20 companies engaged in apparel Mass Customization to obtain first hand and accurate information on current practices.

Your answers are held confidential and will be released only as summaries in which no individual firm's answers can be identified. A copy of the compiled results of this survey will be sent to you.

Should you have any question or comments about this survey please e-mail Muditha at: mmsenana@unity.ncsu.edu

Thank you for guiding the development of mixed manufacturing model and ensuring its relevance for industry.

Sincerely,

Trevor J. Little, Ph.D.
Professor and Head

cc: Mr. Muditha Senanayake

PS: This survey is color-coded and may be filled out by different departments.

APPENDIX C3: INTERMEDIATE "THANK YOU" LETTER

North Carolina State University is a land-Grant university and a constituent institution of The University of North Carolina

Department of Textile and Apparel Technology and Management
www.tx.ncsu.edu/tam/

NC STATE UNIVERSITY

College of Textiles
2401 Research Drive
Raleigh, NC 27695-8301
919.515.3442 (telephone)
919.515.3733 (fax)

Date

Mr./Ms. *First Name Last Name*
Position
Company Name
Address

Dear *First Name*:

Thank you for participating in the recent "Survey of Current Mass Customization Practices" conducted as a part of the Ph.D. dissertation research by Muditha Senanayake. We are pleased to see this amount of interest in the subject of apparel mass customization and we are in the process of collating and analyzing the information. We are especially grateful for those that responded to this study of Apparel Mass Customization Practices. Although the response rate is 70% we would like to encourage those few non-respondents to do so before February 6, 2004. Once the data is analyzed and included in the dissertation, a copy of that part of the dissertation will be sent to those who participated in the survey.

Should you have any question or comments about this survey please e-mail Muditha at: mmsenana@unity.ncsu.edu

Thank you for guiding the development of mixed mass production, mass customization apparel manufacturing and ensuring its relevance for industry.

Once again, thank you for your participation.

Sincerely,

Trevor J. Little, Ph.D.
Professor and Head

cc: Mr. Muditha Senanayake

APPENDIX D

CASE STUDY INSTRUMENT

Case Study Instrument

Case Study Questions for the Research in Mixed Mass Production and Mass Customization: Best Practices for Apparel

Company Information

Company ________________________ Date of Case Study _____________________

Name of Individual Being Interviewed ______________________________________

Title ____

Telephone #______________________ Fax # ________________________________

E-mail Address ____

1. Order Process and Management

- How does the ordering process take place for MP and MC orders?

The discussion requires to address the customization options and how the customer idea is transferred in the order, what technologies use, order frequency, quantity, delivery deadlines, returns, through put times and developments needed.

2. Pre Production

- How are pre-production functions taken place for MP and MC orders?

Information to address supplier arrangements, inventory levels, cut order planning, order release, pattern production/alteration and sample procedures, technologies, marker making, through put times and required developments.

3. Manufacturing - Cutting

- How are cutting room functions taken place for MP and MC orders?

Information to address spreading, lot size, cutting, quality assurance and control, through put times, technologies, order tracking and expected developments.

4. Preparation for Sewing

- How are sewing preparation functions taken place for MP and MC orders?

Information addressing the manufacturing systems, order tracking, bundle or unit preparation, throughput times, technology, and expected developments.

5. Manufacturing - Sewing

- How are sewing functions taken place for MP and MC orders?

Information to address throughput times, technologies, order tracking, order sequencing, product variety based on Extent and Points of Customization, operator skills, system flexibility, efficiencies, quality assurance and control, rework and returns, setup delays, capacities and required developments.

6. Finishing & Packing

- How are finishing and packing functions taken place for MP and MC orders?

Information to address throughput times, tracking, technology, finish goods inventory, customizing from inventory, and expected future developments.

7. Shipping

- How does the shipping process organize to handle MP and MC orders?

8. Finance

- How does the cost and profit structure can be explained in relation to MP and MC?

Information to address the cost differences for MP and MC, cost benefits of MC, price premiums, customer satisfaction, customer loyalty and manufacturing costs.

9. General

- How do you see the mixing of customized apparel in MP manufacturing?

Information to address the viability of mixed or separate MP/MC manufacturing, meaning of mass customization, technology readiness, flexibility, tracking, systems and processes.

APPENDIX E

PERSONAL COMMUNICATION

Interview Instrument

Interview Questions for the Research in Mixed Mass Production and Mass Customization: Best Practices for Apparel

Information of the Interviewee

Date of Interview ____________________

Name of the Expert Being Interviewed ___________________________________

Title ____

Telephone #_____________________ Fax # ________________________________

E-mail Address ____

1. Definition & understanding of mass customization

- What do you really mean by apparel mass customization?

The discussion requires addressing the experience in apparel mass customization and how to define MC, as the understanding of MC means different to different people (for example, is making variety to select from considered as mass customization?)

2. Mass-customized apparel manufacturing

- What are the current MC apparel manufacturing practices?

Discussion to address the suitable manufacturing systems, production unit (single, bundle), leadtimes for domestic and out sourcing, countries to out source, customization from inventory and customized manufacturing limitations with existing systems

3. Mixed MP and mass-customized apparel manufacturing

- What is the possibility of mixed manufacturing in the same production line?

Discussion to address the issues anticipate in mixing, technology available to overcome these issues, problems of tracking, manufacturing system requirements, and producing separately in different production lines.

4. Extent of customization

- What is the Extent of Customization available in the industry and how Points of Customization affect the manufacturing?

Information addressing the available apparel categories for customization, the extent and critical points of customization compared to what is introduced in the research (Design, Fabrication, Feature, Fit and Post Production customization), and what effect the extent has on mixed manufacturing.

5. Technology available for readiness in MC

What are the highlights of technology that aid mass-customized apparel manufacturing?

Information addressing the role of supporting technologies; information technology for elicitation and transfer of information to be accessed as needed in the supply chain, technologies such as digital printing and body scanning for manufacturing, RFID and Barcode for order tracking, technology that supports logistics, etc and how these technologies can aid the mixed MP and MC manufacturing.

6. Cost and benefits of MC

- What can you say about the costs and benefits of MC compared to MP?

Discussion to address costs and benefits as a whole taking in to consideration the early cash flow, profit margins, low returns, low mark downs, high customer satisfaction and loyalty, etc. against higher per piece inventory, shipping, order handling and manufacturing, etc. Also to address the out come that can be expected with mixed MP and MC manufacturing.

7. Future of apparel MC

- What do you think about the future of MC, particularly in relation to apparel?

8. Other possible contacts

- Are there other persons you might recommend that I should speak to regarding mixing MP and mass-customized apparel manufacturing?

Name____

Title____

Contact Information____

APPENDIX F

PERMISSION TO USE THE PAPER IN DISSERTATION

Subject: Re: Permission to use the conference paper in the dissertation
From: "Xiao-ming Tao [ITC]" <tctaoxm@inet.polyu.edu.hk>
Date: Sun, 07 Dec 2003 08:24:01 +0800
To: <mmsenana@unity.ncsu.edu>

Permission granted.

Rgds.

XM Tao

Prof. Xiaoming Tao
Chair Professor and Head
Institute of Textiles and Clothing
The Hong Kong Polytechnic University
Hong Kong
Tel: 852-27666470
Fax:852-29542521
email:tctaoxm@polyu.edu.hk

Subject: Re: Permission to use the conference paper in the dissertation
From:"Kin-fan Au [ITC]" <tcaukf@inet.polyu.edu.hk>
Date:Sun, 07 Dec 2003 08:23:55 +0800
To:<mmsenana@unity.ncsu.edu>
CC:"Xiao-ming Tao [ITC]" <tctaoxm@inet.polyu.edu.hk>

Dear Senanayake,

As you are the author of the paper mentioned, the Conference Organiser would allow you to use it in your PhD dissertation.

Regards.

KF AU
Conference Secretary(ATC-6)
On behalf of Conference Chairman

>>> mmsenana <mmsenana@unity.ncsu.edu> 12/07/03 12:48AM >>>
Professor TAO Xiao-ming
Chairman of the organizing committee
6th ATC - 2001

Dear Dr. Xiao-ming

My research paper "Measures for new product development" was published in the 6th ATC in 2001 and would want to obtain permission from the publisher of the conference proceedings to be used it in my Ph.D. dissertation . Please let me know how I can proceed in getting permission.

Thank you,
Sincerely,

Muditha Senanayake
--
Muditha M. Senanayake
Research Assistant, Ph.D.Candidate
College of Textiles, Dept. of TATM
Campus Box 8301, Research Drive
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Tel: 919 515 6620
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