ABSTRACT

OUTLING, CORA DENISE SMITH. Process, Fit, and Appearance Analysis of Three-Dimensional to Two-Dimensional Automatic Pattern Unwrapping Technology. (Under the direction of Dr. Cynthia L. Istook).

Innovative technology in various forms has been implemented into the apparel industry over the last few decades. The creation of patterns for garment production was revolutionized with the implementation of Computer-Aided-Design technologies such as digitizing, computer grading, and pattern design systems. Recently, 3D body scanning technology was developed and used to assist in numerous areas of apparel product development from measurement extraction to sizing and body shape recognition. More currently, in 2004 a new opportunity to develop patterns directly from 3D body scans was developed. This technology, called three-dimensional (3D) to two-dimensional (2D) pattern unwrapping, is the future of automated apparel pattern development. However, in order for companies to utilize this technology, an assessment of the process of acquiring the patterns, as well as the fit and appearance of the garments produced must be completed to determine if the system works successfully and is a feasible endeavor.

The purpose of the study was to analyze the process, fit, and appearance of the resulting garments from NX-12's 3D to 2D pattern unwrapping system. To obtain this goal a garment evaluation tool was created and used to assess the fit and appearance of the garments. Prior to assessing the garments fit and appearance, an evaluation of the process of developing the 3D extraction and the 2D pattern was also conducted. Lastly, the participants' evaluation of the garments created was analyzed.

Using the data collected, results showed that the system had a number of problems associated not only with the process of creating the garment, but also with the garments themselves. Overall, the issues that occurred were universal to all the participants and therefore could be anticipated and corrected with the addition of parameters. Other issues may be attributed to the 3D body scanner and the respiration and stance of the participants as found from other studies. Participants said they were comfortable with the 3D scanning process and interested in using the technology again. In general, participants had no clear issues with the process and felt the pant pattern, the one with the most parameters in place, fit better than the traditional off-the-rack pants available.

The findings of the research is important to aid in the development of the 3D to 2D pattern unwrapping software system, as well as to determine consumers interest in the technology. This research will benefit the apparel industry mainly because the 3D to 2D pattern unwrapping system is an extremely innovative method of apparel pattern development that has the potential to decrease the time, effort, and the cost of traditional Made-to-Measure mass customization.

PROCESS, FIT, AND APPEARANCE ANALYSIS OF THREE-DIMENSIONAL TO TWO-DIMENSIONAL AUTOMATIC PATTERN UNWRAPPING TECHNOLOGY

by
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DEDICATION

I dedicate this degree
to my loving and forever supporting husband,
***Justin Nathaniel Outling**.*

Thank you

BIOGRAPHY

Cora Denise Smith Outling, daughter of Raymond Edward Smith, Jr and Belinda Michelle Smith (Green), was born on November 23, 1983 in Fayetteville, NC. At very young age her family moved to Frankfurt Germany where she attended grade school until her return back to the states. She received her High School diploma from Eastern Alamance High School in Mebane, NC. In August of 2001, she began pursuing her Undergraduate degree at the University of North Carolina at Greensboro where she developed a high level of pattern manipulation and textile product design skills. In August of 2005, following completion of a one and a half year internship as Assistant Researcher and Product Developer at Wells Hosiery and Apparel Mills, Inc in Asheboro, NC, she received her Bachelor's of Science Degree in Textile Products Design and Marketing with a concentration in Design. Directly following graduation, she began pursuing her Master's degree in Textile and Apparel, Technology and Management at North Carolina State University. After receiving her Master's of Science Degree, Cora plans to continue her career in apparel product development.

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Chapter 1: INTRODUCTION

The apparel industry is comprised of an immense global system that incorporates numerous individuals and companies from fiber to finished product. For a company to survive in the apparel supply chain it must have a way of catching the attention of the consumer in hopes that the consumer will ultimately purchase its product over that of the competition. In the past, consumers tolerated products that did not meet their expectations due to lack in product offerings. This however has changed, and consumers want and expect immediate, personalized services and more variety in product offerings (Fralix, 2001). One resource that fulfils the consumers' need for personalization and product differentiation is Made-to-Measure mass customization (Zipkin, 2001). Mass customization is defined as the integration of standardized processes of mass production with information technology that permits efficiently producing individually tailored products and/or services on a large scale (Anderson et al., n.d., & Zipkin, 2001). Since Stan Davis (1987) coined the term in his book Future Perfect manufacturers have been struggling to meet the wants and needs of their consumers without sacrificing the efficiencies and profits gained through mass production. Pine further elaborated on Davis's idea by asserting that mass customization is a remedy for market turbulence attributed to the consumers' demand for product variety and uniqueness (Ulrich, Anderson-Connell, & Wu, 2003).

Mass customization is considered to be a halfway point between the dramatically different poles of mass production and traditional craft customization. This is because mass customization offers individualized products at large quantities, but unlike craft customization, does not alienate or change the original market by incurring high additional cost (Piller, Moeslein, & Stotko, 2004). Currently, the apparel industry focuses on dimensional customization and modular customization. In modular customization, consumers can pick modules or "building blocks" of the garment to create an individual product. Dimensional customization may also incorporate modular customization with the added ability to create garments based on a person's specific measurements. (Anderson, 2003)

The first large company to offer customized apparel in the market place was Levi Strauss and Company. Their product called "Personal Pair" was first launched in 1995. The company then renamed their Made-to-Measure product "Original Spin" and is offering it in a handful of Levi's stores. Since Levi's introduction of mass customized jeans, other companies have been offering new lines of mass customized products. For example, companies such as Lands' End launched their first products in 2001, and JC Penney followed suit in 2005. (Cornell University, 2003, & Lohr, 2003)

New Mass Customization Technology

Innovative technologies have been continuously implemented into the apparel industry so as to increase efficiency and often to produce higher volumes of products in less time (Loker & Oh, 2002). These two aspects are keys to being competitive in the apparel mass production arena. However, with the increase in consumers' needs for variation in apparel offered in the marketplace, a new technology has been developed primarily for apparel mass customization. This technology is 3D body scanning, and similar to prior ground-breaking technologies it can be used to increase efficiency and speed in apparel product development. Many companies use 3D body scanners to obtain measurements of the consumer's body or create a virtual image of the consumer for digital use. However, 3D body scanning can be used for more than just measurement extraction and virtual modeling. It can also be used to create basic garment patterns for the consumer in just minutes. This innovative form of apparel pattern development is called three-dimensional (3D) body to two-dimensional (2D) pattern unwrapping. Three dimensional to two dimensional pattern unwrapping technology may eliminate the need to alter basic blocks and slopers according to measurements, and open up the opportunity to create garments directly from the individual's body image.

Three dimensional to two dimensional pattern unwrapping technology can be an effective means to creating a competitive advantage via product differentiation, ease in product development, increase in efficiency, and decrease in lead time (Hwang, 2004). This is because apparel product development currently requires specialized manual intervention and even with current apparel technology implemented by manufacturers today there is still a need for expert supervision in the product development process. However, automation aids in decreasing the amount of skilled labor needed for various product development processes. Innovative automation technologies such as automatic 3D to 2D pattern creation can therefore reduce the need for specialized manual intervention while at the same time address the consumers want for product uniqueness, quality, and value. (Kang & Kim, 2000)

However, 3D to 2D pattern development technology has the problems that are associated with ground-breaking technology in that it is not perfected. One problem is that once the pattern is translated from the scanner and entered into a Pattern Development Software (PDS) system there are no set of instructions that define the steps that need to be taken to make the pattern a useable basic block. Also, due to the technology being very new to the marketplace, there has not been a complete assessment of the fit and appearance this product produces for various shapes and sizes of individuals. This assessment can benefit the industry because fit is such a pervasive issue in apparel products, which has lead companies industry wide in trying to discover techniques that will create better fitting garments for individual bodies (Cho et. al., 2005). Three dimensional to two dimensional pattern unwrapping may have this ability but without an assessment, confirmation that the 3D body image can be successfully translated into a correctly fitting 2D pattern is unknown and therefore must be done to insure the program is a feasible endeavor.

Research Objectives

This research will focus on 1) increasing the knowledge about the 3D to 2D pattern unwrapping software, 2) determining how well the system works for various body shapes and sizes, and 3) gaining knowledge of the consumer's reaction to the process and fit of the 3D to 2D garments. Research objectives are as follows:

1. To create an evaluation tool that can be used to assess the fit and appearance of garments.
2. To determine the participants' current fit issues with off-the-rack apparel products.
3. To determine participant reaction to the 3D body scanning process.
4. To identify the process that will enable 3D to 2D patterns to be used for garment design.

5. To determine how all participants' 3D to 2D patterns should be changed to be in accordance with the evaluation tool.
6. To determine how groups of participants' 3D to 2D patterns should be changed to be in accordance with the evaluation tool.
7. To determine how participants rate the fit of the garment made from the 3D to 2D system.

Study Limitations

This study was limited by the following factors:

- The study participants were all obtained via a convenience sample that included only North Carolina residences who were primarily college age students.
- The 3D virtual images of the participants were obtained using only the $[TC]^2$ 3D body scanning system.
- The extraction of the 3D to 2D garments were done using only $[TC]^2$'s NX-12 3D to 2D pattern unwrapping software program.
- The 3D to 2D patterns were only imported and tested in the Gerber AccuMark PDS software program.
- The 3D to 2D patterns were only cut using the Gerber cutting system

Chapter 2: LITERATURE REVIEW

In this Chapter, related literature is presented in the following categories: the history of pattern making, garment fit and appearance, apparel sizing, apparel customization technologies, mass customization, Made-to-Measure industry leaders, and importance of new technology.

The History of Pattern Making

There are three main ways an apparel pattern can be made, each of which influences the labor spent creating the garment and the final cost of the garment. The three methods of creating an apparel pattern are draping, pattern drafting, and flat-pattern engineering. These methods can be combined to produce the product the company needs in order to meet their consumer's standards. Draping (see figure 1) is a way of creating a pattern by shaping the fabric around a body to create a 3D fabric pattern. This fabric pattern is then translated onto paper via hand or digitizer. Overall, this process is more expensive and therefore is primarily used for the development of higher priced garments such as woman's formalwear. (Keiser & Garner, 2003)

Figure 1. Students from West Valley College (2004) draping garments.

Pattern drafting is the next form of pattern development. This is done by taking the measurements of an individual and adding ease to those measurements for pattern creation. The measurements are then used to make a pattern from scratch specifically for that consumer. This process can be done by hand or computer. However, similar to draping it is usually done for higher priced garments. (Keiser & Garner, 2003)

The last form of pattern development is flat pattern engineering. This is the most common form of pattern development used in the apparel industry today. Companies go about making new patterns using the flat pattern method by taking a perfected basic block and altering it to create a new garment pattern. This can also be done to a basic sloper, which is a successful pattern of a style with no seam allowance or style ease. These slopers and blocks can then be altered using the computer or by hand (Keiser & Garner, 2003). However, unlike pattern drafting, in order to produce a garment that will fit appropriately for the individuals in a particular size category pattern grading must be used (see figure 2). Pattern grading is the process of systematically increasing and decreasing the dimensions of a block or sloper into a range of sizes for mass production (Kang & Kim, 2000; Moore, Mullet, & Young, 2001). The process of grading is very tedious and requires a great level of concentration and acumen. Often the accuracy of the final graded garment is influenced by the skill of the grader (Kang & Kim, 2000).

Figure 2. Hand pattern grading machine retrieved from Fashion-Incubator, 2006.

Numerous sectors of the textile and apparel industry have been affected by globalization as well as the onset of the information age. These two drivers have made the industry quicken its pace and introduce new technology that will efficiently and productively meet the needs of its consumers. This is especially true for the manufacturing side of the industry where there is an unlimited need for speed and efficiency in the product development process. This is why over the past few decades there has been a steady increase in the adoption of Computer-Aided-Design (CAD) systems (Yan & Fiorito, 2002). For example, in the late 1960s computerized grading was introduced (Keiser & Garner, 2003). This process was much quicker than manual grading because once the grading system was developed it could be applied to the basic block and/or new garments quickly.

Computerized grading was followed by computerized pattern making in the 1980s (Burns & Bryant, 1997). Below shows the evolution of pattern making and the inception of various information and technologies that revolutionized apparel pattern development (see figure 3).

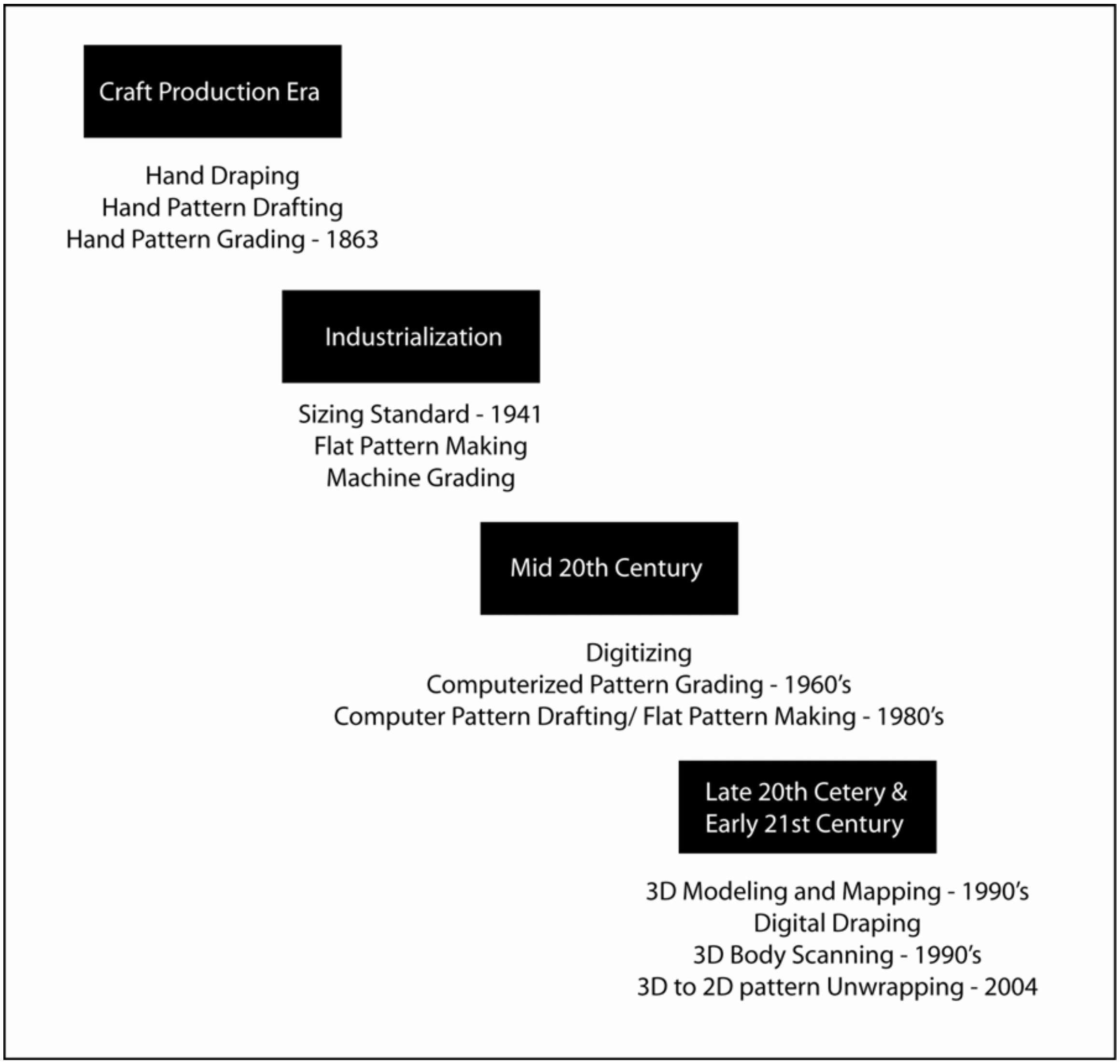

Figure 3. Timeline of apparel technology for product development created using information retrieved from Burns & Bryant, 1997; Keiser & Garner, 2003; Standardization of Women's Clothing, n.d.b.; [TC]², n.d.d.

Garment Fit and Appearance

Key Fit Locations

There are key locations on the body that are important to check in order to create a garment with "good" fit. These key locations are:

Shoulder length. Shoulder length is the measurement taken between the base of the neck and the shoulder edge (Shepherd, 1997). The shoulder seam should look smooth across the top of the shoulder starting from side neck and ending at the point where shoulder and arm connects (Shepherd, 1997).

Bust circumference. Bust circumference is the measurement parallel to the floor that is taken at the widest part of the bust across the bust points and under the arm (Shepherd, 1997).

Waist circumference. Waist circumference is the measurement parallel to the floor that is located at the point where the body bends or the "natural waist" (Shepherd, 1997). This measurement should be taken to fit close to the body, but not so tight that it holds in or constrict the body in any way (Shepherd, 1997).

Hip circumference. Hip circumference is the measurement parallel to the floor that is located at the fullest part of the body between 7 to 9 inches below the waist (Shepherd, 1997). The hip and seat curve "should follow the contours of the body smoothly" (Editors of Creative Publishing International, 1987).

Back waist length. Back waist length is the vertical length (perpendicular to the floor) measurement that is taken from the bone at the base of the center back neck and extends to the center back waist line (Shepherd, 1997).

Sleeve length. Sleeve length is the vertical measurement (perpendicular to the floor) that is taken from the mid side point where the shoulder attaches to the arm to the mid side wrist bone (Shepherd, 1997). The sleeve should hang straight down to the elbow and then bend slightly toward the front of the body (slightly forward of the side seam) following the contours of the arm when naturally relaxed (Shepherd, 1997).

Crotch depth. Crotch depth is the measurement taken while seated in a chair. It is the vertical measurement (perpendicular to the floor) from the side waist point to the chair top (Shepherd, 1997).

Crotch length. Crotch length is the measurement taken from the center back waist point, between the legs, and to the center front waist point. The front and back crotch lengths are determined by pinpointing the mid-point between the legs (Shepherd, 1997). Furthermore, the crotch seam "should follow the contours of the body smoothly" (Editors of Creative Publishing International, 1987, p. 13).

Armhole. Armhole should not have any large space evident between the arm and the fabric (Joseph-Armstrong, 2006).

Traditional Fit

According to the literature a traditionally fitted garment is one that lies close to the body and follows the natural shape of the individual wearing the garment. This allows for little wearing ease because of its conservative and classic design. Some well known traditionally fitted garments are tailored jackets, tailored skirts, and tailored pants. A traditionally fitted garment has the most ease evident in the hip area to allow for sitting and movement. For around the bust the ease is usually around 2 inches. For the waist it is 1 inch and for the hips it is 3 inches. Overall, the traditional fit is considered to be the most precise garment fit. (Editors of Creative Publishing International, 1987)

Design Principles

According to the literature achieving a “good” fitting garment is based on four principles. These principles are design, fabrication, appearance, and comfort. (Shepherd, 1997)

Principle I: Design. The design of the garment affects the fit of the garment. A loose fitted design is acquired by adding more wearing ease than movement deems necessary, while a close fitted design generally has less ease than is necessary for comfortable movement. A garment with a close fitted design is meant to show off the body underneath, while a loose fitted garment design camouflages the body. To create these different garment designs, ease at the seams and darts can be decreased or increased. A loose garment can also be acquired by increasing the fullness in the fabric by adding gathers, shirring, pleats, and releasing seam lines, darts, tucks, or other stitched fitting devices. Along with changing ease, other techniques can be used to create different designs such as the bias cut, which is used when creating a closer fitted garment. (Shepherd, 1997)

Principle II: Fabric. Fabric is the next important element that impacts the fit of the garment. It is considered to be the most important thing to consider when trying to achieve “good” fit. Some fabric characteristics can alter how the garment will fit and/or appear to fit. For example, a thinner weight knit may cause a garment to be more relaxed and stretchy than a heavier weight knit fabric. Fabrics like knits, which have stretch, will produce a garment with more give and therefore can be used with patterns that are dimensionally smaller or the same size as the body underneath. However, fabrics that are thick and have little give will need to be used with patterns that are significantly larger than the body that it is intended to fit to allow for movement and comfort and to also accommodate the thickness/ bulk of the fabric. However, if the same large pattern used with a thicker fabric was used for a thinner fabric the final garment may be too large on the body because of the excess room that is not taken up by the bulk that was present in the thicker fabric. (Shepherd, 1997)

Principle III: Appearance. Appearance is the third characteristic that impacts the fit of a garment. To ensure a "good" appearance the style lines such as darts and seams have to be in the right place in relation to the body underneath. If these fitting devices are in the right location the garment will appear to be smooth along the contours of the body. Smooth shoulder seams, straight hanging sleeves, flat seam appearance, level hem line, appropriate located darts, and level waist seam all impact the appearance of the garment (Shepherd, 1997). Below is a list of major areas of the body that impact appearance, and how these areas should look as it relates to the garments location on the body.

- Seams should be straight with no puckering or waving (Shepherd, 1997).
- Full circumference of hems should hang parallel to the floor (Shepherd, 1997).
    - Pant hem "should touch the top of shoe" (Editors of Creative Publishing International, 1987, p. 13).
    - Sleeve hems "should end at the wrist bone when arm is slightly bent. Jacket sleeves should allow ¼ inch to ½ inch of blouse to show. Coat sleeves should

hang ¼ inch to ½ inch longer than wrist bone to cover blouse sleeve” (Editors of Creative Publishing International, 1987, p. 13).

- Darts should point toward, but not completely to the fullest part of the area of shaping interest; rather it should fall slightly shorter (Shepherd, 1997). Furthermore, darts should end with slight fullness and should be changed if there is too much fullness or if they end with stress lines (Joseph-Armstrong, 2006).
    - Skirt darts closest to the center front should align with the body’s princess line (Joseph-Armstrong, 2006). Back skirt darts “should stop ½ inch to 1 inch short of the fullest part of the seat” (Editors of Creative Publishing International, 1987, p. 13).
    - Bust shaping darts “should follow bust contours and bust darts should end 1” to 1.5 inches from the bust point for sizes 14 and smaller and 2 inches to 2.5 inches for sizes 14 and larger” (Editors of Creative Publishing International, 1987, p. 13). The center front waist dart should be located on the waist line according to pre-determined standard calculations along with personal judgment.
        - If the waist measures: (Handford, 2003)

Total Waist Measurement	Center Front to Dart
22" - 23"	2 ½"
24" - 25"	2 ¾"
26" - 27"	3"
28" - 29"	3 ¼"
30" - 31"	3 ½"
32" - 33"	3 ¾"
34" - 35"	4"
36" - 37"	4 ¼"
38" +	4 ½"

- Bodice back "should fit smoothly across the back and contour to the body's shape" (Editors of Creative Publishing International, 1987, p. 13).

Garment balance on the body is another important aspect of "good" fit and appearance. The garment should look balanced on the body, meaning that certain locations of the garment should look parallel or perpendicular to the floor when the body is standing erect. The grain is the main indicator of balance. Grain is the direction in which the yarn is woven or knitted. At the chest, waist, and hip the grain line should appear to be completely parallel to the floor. The vertical line running from center front and center back to the floor is determined by the literature to be the plumb line. This is the main determiner of a balanced figure and should run perpendicular to the floor. The chest, waist, and hip lines are determined to be the horizontal balance lines of the garment and should run parallel to the floor as well as form right angles or be squared to the plumb lines. (Joseph-Armstrong, 2006)

Principle IV: Comfort. Comfort is related to how the garment feels against the body when the individual is wearing it. Some apparel is not meant to be comfortable while other garments are focused on this issue. Comfort for most garments is related to everyday actions that must be done when wearing apparel such as sitting, bending, walking, and reaching. These actions must be performed in the garment without straining the garment and/or seams or feeling compressed or restricted. In order to accommodate these actions comfortably and therefore produce a garment with "good" fit, wearing ease must be added into the garment. Below is a list of the major areas of the body that need added ease for comfort and how much ease is needed for a traditionally fitted garment. (Shepherd, 1997)

- Stress lines will not be present if there is adequate ease (Joseph-Armstrong, 2006).
- Bust ease is usually around 2 inches (Editors of Creative Publishing International, 1987).
- Waist ease is 1inch (Editors of Creative Publishing International, 1987).
- Hips ease is 3 inches (Editors of Creative Publishing International, 1987).
- Neckline ease is “1/8 inch around the front and back” (Joseph-Armstrong, 2006).
- Sleeve ease at the cap should be 1.5 inches for size 10 and larger and 1.25 inches for size 10 and smaller. The amount of ease should be the same for the front and back sleeve cap and should not pucker or pull when connected to the armhole. (Joseph-Armstrong, 2006)
- Sleeve ease at the bicep should be 2 inches (Joseph-Armstrong, 2006).

Apparel Sizing

Mass customized products offer a unique solution to a problem that the consumer currently faces in the marketplace, which is garment fit (Zipkin, 2001). In the early Twentieth Century mass produced off-the-rack clothing fit poorly. A need for a standardized sizing system was apparent in order to provide properly graded apparel. Therefore, in 1937 the U.S. Department of Agriculture (USDA) decided to study women’s body measurements (anthropometry) with hopes to develop an industry sizing standard (Standardization of Women’s Clothing, n.d.c.). This study concluded in 1941 and consisted of 14,698 subjects primarily between the ages of 18 and 30. However, not until almost 20 years later, 1958, did this study become a standard in the industry with the release of CS 215-58 U.S. Department of Commerce voluntary clothing standards. Revisions were ultimately made to this standard in 1971. The revision included data collected from a survey administered in 1962 by the National Center for Health Statistics that found that women were larger than the 1958 standard accommodated. Therefore, the revision to the standard included increasing the bust by one grade as well as eliminating "slender" and "full" hip options. It also eliminated the "tall" option for juniors and women's sizes. Later, in 1995, the American Society for Testing and Materials (ASTM) developed a sizing standard. This standard was created by adopting the previous 1971 standards measurements and slightly updating them to go along with the industry's current practices. Other surveys done to acquire a better sizing standard for the industry were the Civilian American and European Surface Anthropometry Resource (CAESAR), SizeUK, and SizeUSA. (Newcomb, 2005)

Despite the USDA, ASTM, and other apparel sizing studies, fit is still an issue today. Many consumers have concerns with 1) inconsistency in sizing within and between brands, 2) the lack of sizes that are bigger or smaller than the majority of the population, and 3) the psychological impact on body image from purchasing a size that is different than that they desire to wear (Connell, Ulrich, & Brannon, 2002). This consumer sentiment has been echoed by leaders throughout the apparel industry. At the 2006 SizeUSA Conference, Robert Holloway of Archetype Solutions stated "… retailers have been quite astute at predicting the right style, fabric, and color, but fit remains a pervasive problem." Jim Lovejoy (2006), director of the SizeUSA project for [TC]^2 stated:

> "If you look at the grade rules for most manufacturers today, they do not reflect what we are finding in our sizing survey." "I have shown several manufacturers the bust, waist and hip measurements of women who say

> they wear size 8-10, and they are surprised to see how much larger all three of the measurements are than their fit specs" accommodate. ([TC]^2, n.d.a.)

Another issue impacting the fit of apparel products is that the measurements used for creating the ASTM sizing standards are based off of decades old (1937-1941) anthropometric data. The Anthropometric data used to create the current ASTM sizing standards for apparel are shown to be non-representative of the American population by the findings found in a study comparing SizeUSA data to current ASTM standards. The SizeUSA data contained scanned images and measurements of 6300 U.S. women. The findings showed that the measurements used by the ASTM junior 6829 and the Missy 5585 standards corresponds 100% to the hourglass body shape for all size ranges. However, the SizeUSA data differs in that only 12.5% of the junior sample and 8% of the missy sample were classified as having an hourglass body shape. This study shows that the bust to waist to hip ratio is inaccurate and therefore the apparel industry's current ASTM sizing standard is not effectively meeting the fit needs of the target consumer. (Newcomb & Istook, 2004) Furthermore, even hourglass shaped females have issues with the sizing of apparel products. This is shown by the findings from a study assessing the fit preferences of young adult females, the majority of which were hourglass shaped. The study found that 64% of them had to alter their ready-to-wear (RTW) apparel products on a regular basis to achieve the desired fit of the garment. The study also found that 54% of the respondents were not satisfied with the fit of the RTW products out in the marketplace. (Connell & Presley, 2005)

The lack of standardized apparel sizing across companies is also a pervasive problem in the apparel industry today. ASTM sizing standards are voluntary and therefore generally aid manufactures in determining the correct measurements needed for a particular predetermined size, such as a size 10. Therefore, many manufacturers interpret and may alter the measurements from the ASTM sizing standards to fit their target consumers' fit preferences. A company uses a fit model, which represents their average consumer, to test the changes made to the voluntary ASTM standard (Connell & Presley, 2005). This leads to different manufacturers using different measurements for each size. This problem affects retailers, manufacturers, and consumers alike (Fashion-incubator, 2006). For example, A size 10 at JC Penney measures 36.5 bust, 28.5 waist, and 39 hip (JC Penney, n.d.) while a size 10 at Old Navy measures 37.5 bust, 29.5 waist, and 40 hip (Old Navy, n.d.). This leaves the consumer with two distinctively sized garments, and perhaps the need for a different size garment at each store. Therefore, the industry's method of producing off-the-rack garments based off of individual fit model measurements makes it hard for the consumer to judge fit unless they have purchased from that company before or try the product on. Below is a figure developed by Ashdown that depicts the variables that are used to determine a company's sizing system. The main categories depicted are A) acquiring measurements, B) assessing the consumers' fit issues, C) communicating to the consumer the size of the garment, and D) determining the fit of each individual style based off of the design features of the garment. (Connell & Presley, 2005)

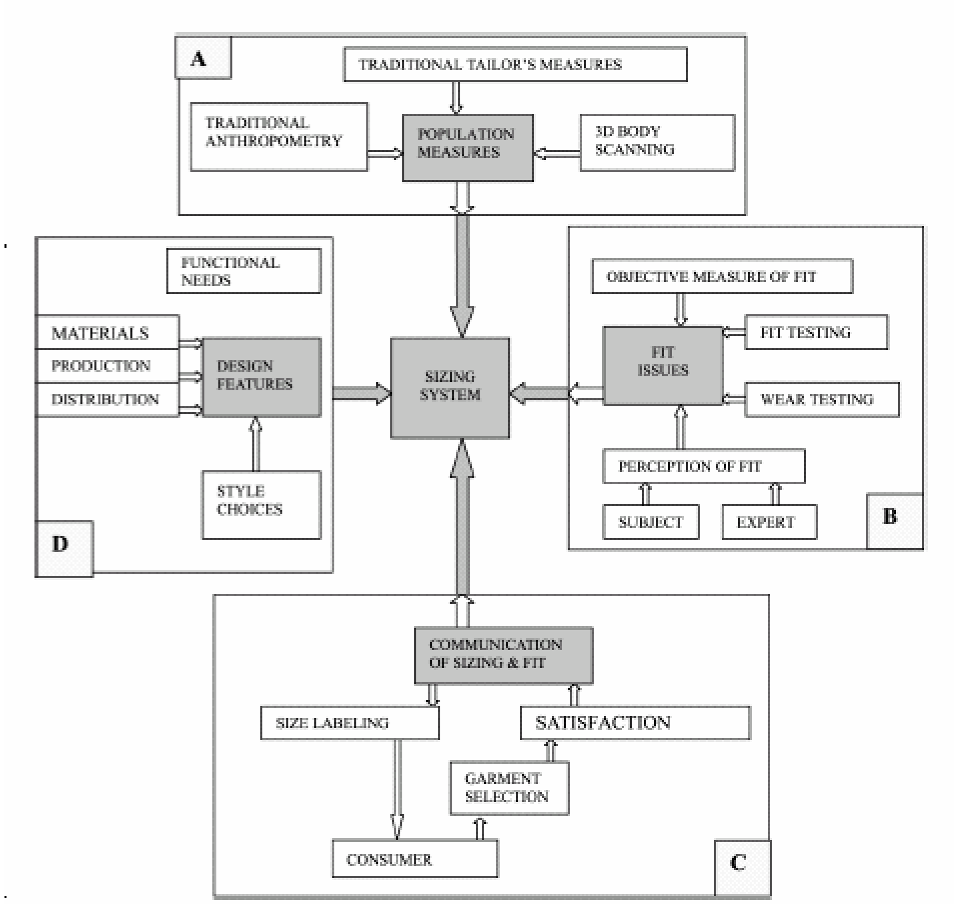

Figure 4. Ashdown's 2000 model for the development of a sizing system retrieved from Connell & Presley, 2005.

Inconsistency in sizing makes it understandable why only approximately 40% of the population can purchase off-the-rack apparel and obtain the desired fit. Accordingly, over half the population serves as potential consumers for Made-to-Measure apparel (Glock, & Kunz, 2005). If the available clothing does not fit, the consumer will be more likely to develop dissatisfaction about the product (Zipkin, 2001). Companies that produce Made-to-Measure products virtually eliminate poor fit and therefore increase consumer satisfaction.

By offering better fit through mass Made-to-Measure customization a company offers the consumer a product that is perceived to be of better value than other products on the market. According to Lands' End, 72% of their consumers who ordered customized garments say that they did so because they wanted a better fit. They also spent 39% more annually at their store for these products, which are priced roughly ten dollars more than the same off-the-rack product. These findings further express that mass Made-to-Measure customization acts to differentiate products and gives the consumer a reason to pay more for the specialized product. (Corcoran, 2005)

Mass customization also minimizes the issue of merchandise returns due to poor fit. Merchandise returns cost retailers $28 billion a year according to apparel industry estimates. The highest percent of returns are found in the online and catalogue retailing arena where, at times, returns equal almost 40% of sales. According to consumers, the most frequent reason for these returns is poor fit (Glock, & Kunz, 2005). A study conducted by Lands' End found that internet shoppers reorder customized apparel 34% more often than internet shoppers who order off-the-rack sizes of apparel. Therefore, as concluded from this study, internet shoppers who order customized garments are more satisfied with the product and are therefore more likely to purchase from that company again (consumer retention and loyalty). (Corcoran, 2005)

Apparel Customization Technologies

New innovations in software and technology are a very important means to acquiring success for companies producing mass customized products. Made-to-Measure software has been developed to provide not only a retail interface between consumer and manufacturer, but also make the customization process more automated and successful. The main technologies used in the development of mass customized apparel, is pattern development software (PDS) and 3D body scanning systems.

Pattern Development Software

Pattern Development Software (PDS), also known as Computer-Aided-Design (CAD) systems, is computer technology and programs that are used in apparel pattern development up to the point of production (Glock & Kunz, 2005). These systems work by utilizing basic pattern blocks or slopers that are entered into the computer's memory via a digitizer, scanner, or directly creating it through the program. The patterns are then changed to coordinate data and altered by the user in a number of ways to produce new styles. PDS and CAD technology allows patterns to be changed with ease and accuracy by modifying the lines and points to make numerous basic and stylized pattern pieces. (Glock & Kunz, 2005)

Companies such as Gerber Technology, Inc., Lectra Systems, Inc., Investronica (which was acquired by Lectra Systems, Inc. in 2004), Assyst-Bullmer, and OptiTex have developed PDS systems that can support the alteration of patterns for mass customization. However, the key players in this arena are Lectra Systems, Inc., and Gerber Technology, Inc. (see figure 5). This is because they have gone a step further and have collaborated with producers of 3D body scanning systems. They have added to their software the ability to link their PDS systems directly to the 3D body scanner and internet tools to increase the efficiency of developing Made-to-Measure products. (Lectra Systems, Inc., n.d.c.)

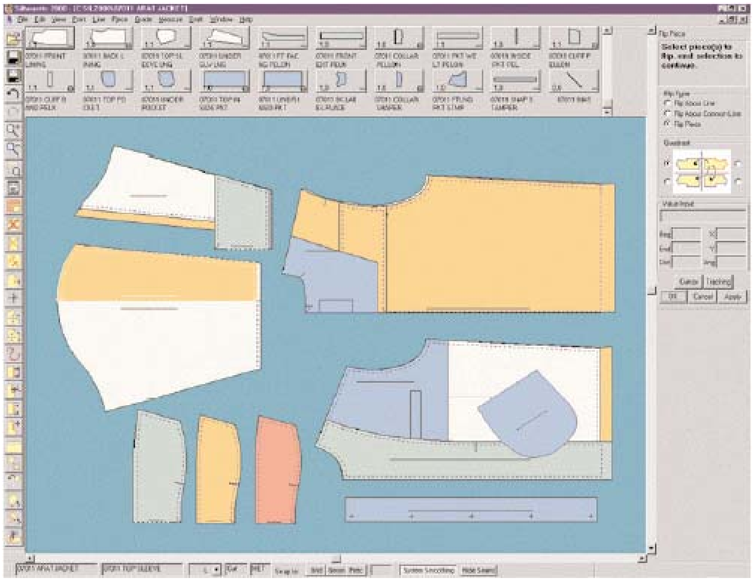

Figure 5. Gerber's AccuMark PDS software system retrieved from Gerber Technology, n.d.b.

While Lectra and Gerber have direct ties to 3D body scanning systems, other producers of CAD programs have developed software modules that can be used to create garments on the 3D scanned image. These virtually draped garments can ultimately be converted into a flat pattern used to create a final stylized product. (OptiTex, n.d.b.)

Advantages to PDS Systems

Pattern design systems have made pattern making easier, as well as a more cost efficient process. The main advantages of using computer-aided pattern making programs are the decreased time it takes to develop a product, the increased accuracy in pattern manipulation, the decrease in ergonomic concerns for pattern makers, and the increased ease to production. (Burns, & Bryant, 1997)

Speed is the most apparent advantage of using PDS versus hand pattern development. For one, basic blocks and slopers can be stored in the computer's memory and retrieved quickly. This avoids the tedious task of manually tracing the block onto paper to prepare it for pattern manipulation. It also allows for easier and faster manipulation of the pattern to create pieces such as facings and interfacings. Hems and seam allowances are also faster to add to the finished pattern rather than re-tracing the pattern by hand and then adding seam allowance and hems to the newly traced pattern pieces. Furthermore, adding identifying marks such as notches, drill holes, grain lines, and annotations to the pattern is quickened by using mouse clicks and typing. Lastly, the speed of actual pattern manipulation is increased with the use of computer-aided design. Fullness, slashing and spreading, and style lines can be executed much faster than the traditional act of manually cutting the pattern and inserting paper into the spread to secure the changes made. (Burns, & Bryant, 1997)

Accuracy is another aspect of pattern making that is enhanced by using computer-aided design. Truing the pattern is made much easier, faster, and more accurate by allowing the computer to measure and correct the seam length. Accuracy is also increased in the pattern making process by eliminating incremental growth that is common in manual pattern making due to the act of tracing with a pencil, and cutting the pattern by hand. (Burns, & Bryant, 1997)

PDS offers the patternmaker an increase in comfort by decreasing stress on the body that is caused by hand pattern making. Bending over a pattern making table is a natural part of manual pattern making. However, with the use of computers these ergonomic concerns are decreased mainly because sitting and using a mouse is much easier on the body than the former. Furthermore, the taxing act of cutting hard pattern paper is usually eliminated with the use of PDS systems. This is because companies who utilize Computer-Aided-Design usually have in place an automated cutting system. (Burns, & Bryant, 1997)

3D Body Scanning Technology

3D body scanning (see figure 6) is one of the newest technologies used for apparel pattern development. It presents the ability for a company to offer its consumers rapid response and a better fitting garment, as well as give the company an opportunity to learn more about their consumer and reduce overhead costs (Keiser & Garner, 2003; Mckinnon & Istook, 2002). The body scanner is used to acquire a 3D replica of an individual's body in digital format ([TC]^2, n.d.b.). The measurements and image taken from the 3D scan can then be electronically transferred into a computer database where an intermediate software program can properly utilize the information for custom clothing or other applications. (Keiser & Garner, 2003)

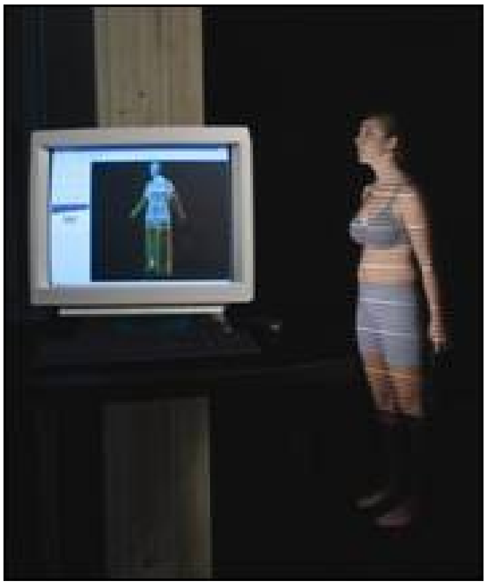

Figure 6. [TC]^2 3D body scanner retrieved from [TC]^2, n.d.b.

One of the first 3D body scanners was developed in the United Kingdom by Loughborough University. This 3D body scanning system used a shadow scanning method to acquire the image of the participant. A camera, a desk lap, a pencil, and a checkerboard were the four components used in the shadow scanning method. The desk lamp was used to illuminate the body of the participant while the camera captured the shadow image produced as the light moved down the body. The captured images were entered into a 3D reconstruction software system to create the 3D image of the body. Another early system also developed by Loughborough University was the Loughborough Anthropometric Shadow Scanner. This system was more automated than the former and was slightly more refined. It utilized a 360 degree platform that the participants stood on. This platform was turned while a vertical slit of light was projected onto the body. A camera then collected the shadow images of the participant captured in the light, and used those images to create a 3D digital image of the participant. (Istook & Hwang, 2001)

Types of 3D Body Scanners

There are a number of body scanners that use various ways of collecting measurements of the human body (Glock & Kunz, 2005). The research shows that there are five major companies that produce 3D body scanning systems that can be used in the textile and apparel industry. These companies are Textile Clothing and Technology Corporation ($[TC]^2$), Cyberware, Inc., Wilks &Wilson Ltd, Telmat Industrie, and Human Solutions. The majority of scanners fall into one of three categories that are classified by the way they acquire the image. According to S. Hwang (2004) the categories are light based systems, laser based systems, and surface tracing systems. $[TC]^2$'s body scanners are light based while Cyberware, Inc.'s WBX and WB4 systems are laser based. Laser and light based machines are the most common body scanners available today. Light based machines are said to be potentially safer than laser based machines since its method of image capturing is very similar to flash photography. They are also faster at scanning than laser and shadow scanning machines, but slower at extracting the measurements from the image. Table 1 is a table of the different machines on the market today. (Istook & Hwang, 2001; [TC]^2, n.d.b.)

Table 1. Istook & Hwang (2001) chart of scanning systems available.

Light-based systems		Laser-based systems		Other systems	
Company	Product	Company	Product	Company	Product
Hamamatsu	Body lines scanner	Cyberware	WBX, WB4	Immersion	Micro Scribe 3D Micro Scribe 3DX Micro Scribe 3DLX Micro Scribe 3DL
Loughborough University	LASS[a]	TecMath	Vitus Pro, Vitus Smart	Carl Zeiss	
TC2	2T4, 3T6	Vitronic	Viro-3D (4L 8C ST), Viro-3D (4L 16C DT), Viro-3D (4L 16CDT colour), Viro-3D	Faro Technologies	
Wicks and Wilson Limited	TriForm, TriForm BodyScan, TriForm3 (Torso Scan), TriForm2 (Headscan), TriForm1	Hamano	VOXELAN		
Telmat	SYMCAD 3D Virtual model	Polhemus	FASTSCAN		
Turing	Turing C3D	3D scanners	REPLICA, Model Maker, REVERSA, Re Mesh, RI Software, PROFA		
Puls Scanning System GmbH	Puls scanning system				
CogniTens	Optigo 100 system				

The size of the machine is a very important characteristic to consider when assessing 3D body scanners. This is especially true in the case of a retailer implementing this technology into their stores. Floor space is extremely valuable in a retail setting mainly because of the cost of the space, and the fact that the more products the consumer has to choose from the more likely they will find something that they want to purchase. The goal of many producers of 3D scanners for apparel is to reduce the size of the scanner to the size of a conventional dressing room. Size is also important from a data management aspect. File sizes of the scans need to be small enough to store, transmit, and pull up quickly for e-commerce and web product development (Istook & Hwang, 2001). Table 2 is a comparison of the booth size and data size of various 3D body scanners on the market today.

Table 2. Istook & Hwang (2001) size chart of 3D body scanners available.

Light projection systems			
System	Booth size (W × D × H in metres)	Volume (W × D × H in metres)	Data size (Mb)
TC2—3T6 system	3.3 × 5.9 × 2.4	1.1 × 2 × 1.1	6Mb
TC2—2T4 system	1.2 × 6.3 × 2.4	1.1 × 2 × 1.1	4Mb
TC2—2T4s system	1.2 × 4 × 2.4	1.1 × 2 × 1.1	4Mb
Hamamatsu – BL	1.59 × 1.67 × 2.75	0.89 × 0.5 × 2	0.3Mb
Telmat—SYMCAD	3.0 × 1.5 × 2.4	0.8 × 1.3 × 2.2	0.25Mb
Wicks & Wilson—TriForm Body Scan	2.5 × 1.5 × 2.4	0.75 diameter × 2 (cylinder)	10Mb

Laser projection systems			
System	Booth size (W × D × H in metres)	Volume (W × D × H in metres)	Data size (Mb)
Cyberware—WB4	3.8 × 3 × 2.9	2 × 1.2 × 1.2 cylindrical	0.8Mb (comp)
Cyberware—WBX	3.8 × 3 × 2.9	2 × 1.3 × 0.5 (elliptical)	0.8Mb (comp)
Vitronic—Vitus Smart	3.1 × 2.5 × 1.85	2.1 × 0.8 × 1.2	3Mb
TecMath—RAMSIS	2.0 × 1.1 × 2.8	0.8 × 0.8 × 2.2	
Hamano—VOXELAN		11 × 0.74	
Polhemus—Fastscan		2 × 2 × 2	

3D Body Scanner Industry Leaders

[TC]^2. [TC]^2 is a company known world wide for their developments in 3D body scanning technology. Their 3D Body Measurement System (BMS) became available for commercial sale in 1998 and was first sold in 1999 to industry leader Levi Strauss and Company. [TC]^2 also provided body scanning systems to the U.S. Navy, North Carolina State University, and Clarity Fit Technologies in that same year. ([TC]^2, n.d.d.) Their system can produce a 3D model of an individual in six seconds using a phase measuring profilometry (PMP) technique. This technique projects white light on the surface of an object while the coupled charged device (CCD) camera linked to a computer captures a

total of four images from each sensor. Each image is then calculated pixel by pixel (roughly 800,000) to determine the pixels 3D data point (Istook & Hwang, 2001; [TC]^2, n.d.b.). These data points are compiled together creating a point cloud which consists of roughly 40,000 points for each subject's body. Once the point cloud is created for each image they are combined together to form a single point cloud of the body (see figure 7). These points can then be used to extract up to 200 measurements automatically in less than a minute (Istook & Hwang, 2001; [TC]^2, n.d.a.) (see figures 7 and 8). The image and measurements are then processed into a computer that is equipped with Windows XP operating system and is compatible with a variety of CAD systems available on the market ([TC]^2, n.d.c).

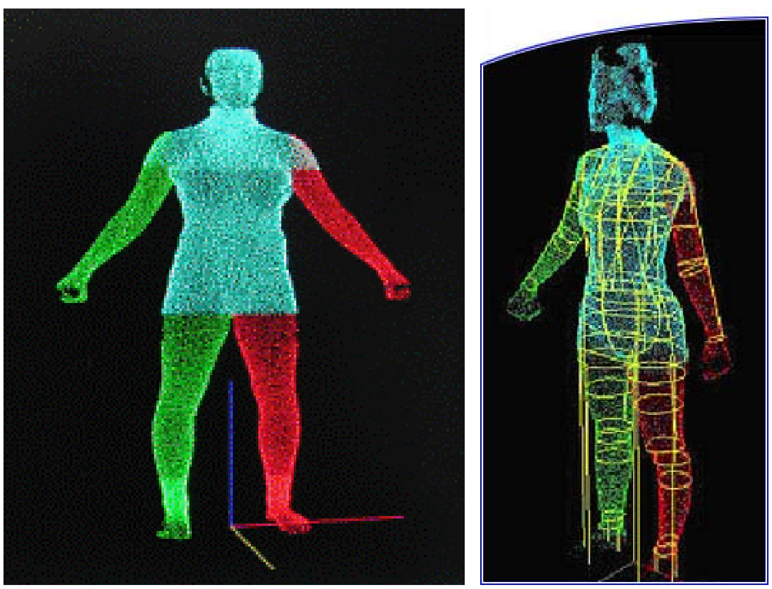

Figure 7. Examples of 3D point cloud data and measurement extraction retrieved from [TC]^2, n.d.c.

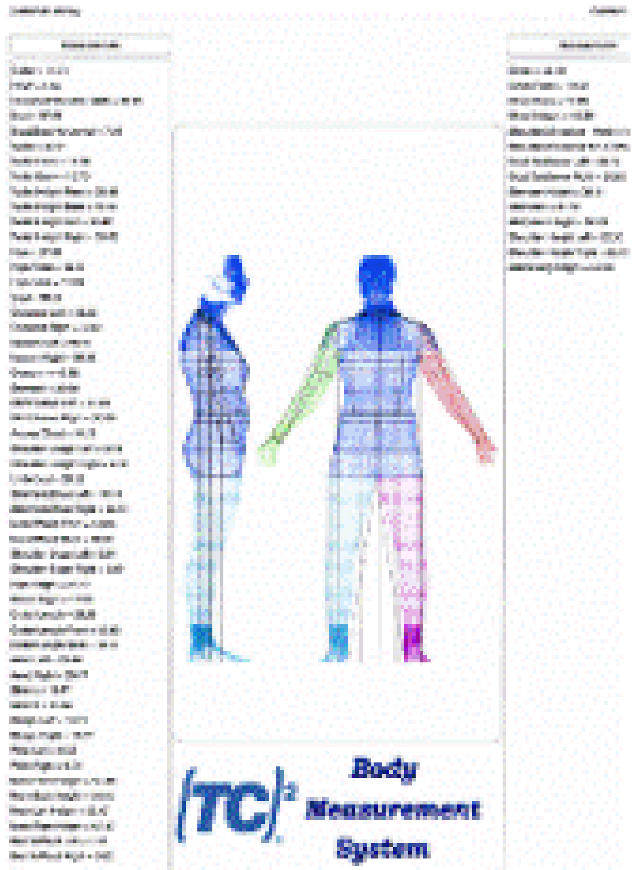

Figure 8. Example of 3D scanner measurement extraction output [TC]^2, n.d.c.

In 2005 alone, 44 NX-12 3D body scanners were purchased worldwide. Some companies that have implemented [TC]^2 body scanning technology are Levi Strauss and Co., Brooks Brothers and Co., LeBon Marche' store, and Benchmark Clothiers. ([TC]^2, n.d.d.)

Cyberware. Cyberware is another company that has developed 3D body scanning technology. Their products are called Whole Body X 3D Scanner (WBX), which is a fully enclosed scanner, and Whole Body Color 3D Scanner (WB4). They both take 17 seconds to create a complete image. These scanners use laser light that is projected around the body and into the cameras located in the scanning heads. Mirrors are used to aid in the data collection process by allowing the light reflected off of the object to be viewed simultaneously from two locations. The light viewed from an angle is distorted by the objects shape. This distortion is recorded by the CCD sensors and combined and used to create the digital replica of the object's shape. (Cyberware, n.d.; Istook & Hwang, 2001)

The WBX scanner (see figure 9) developed in 2000 uses four scanning heads that capture the individual being scanned quickly at a rate of 60,000 points per second. It was developed for use in acquiring measurement data used for apparel product development. Overall, the measurement information can be outputted in over 10 formats. (Cyberware, n.d.; Istook & Hwang, 2001)

Figure 9. Cyberware's whole body X 3D body scanner retrieved from Cyberware, n.d.

The WB4 (see figure 10) has the added ability to not only capture an object's shape but also their RBG color image. This device uses four scanning heads that are located on two stand alone towers. The individual stands on a platform between the free standing scanner towers and waits as the scanning heads move vertically down the tower capturing the figure. This system is more complex to assemble and operate than the

WBX scanning system. It is also a more expensive system costing roughly $350,000 compared to the WBX system that cost $150,000 in 2000. (Cyberware, n.d.; Istook & Hwang, 2001)

Figure 10. Cyberware's whole body color 3D body scanner retrieved from Cyberware, n.d.

Cyberware's DigiSize Software is used to extract and store measurements to be used in various applications. It also aids in the ability to convert the image into VRML (see figure 11) files which can later be used in web applications such as using the individuals duplicate image as a vessel for trying on garments digitally. (Cyberware, n.d.)

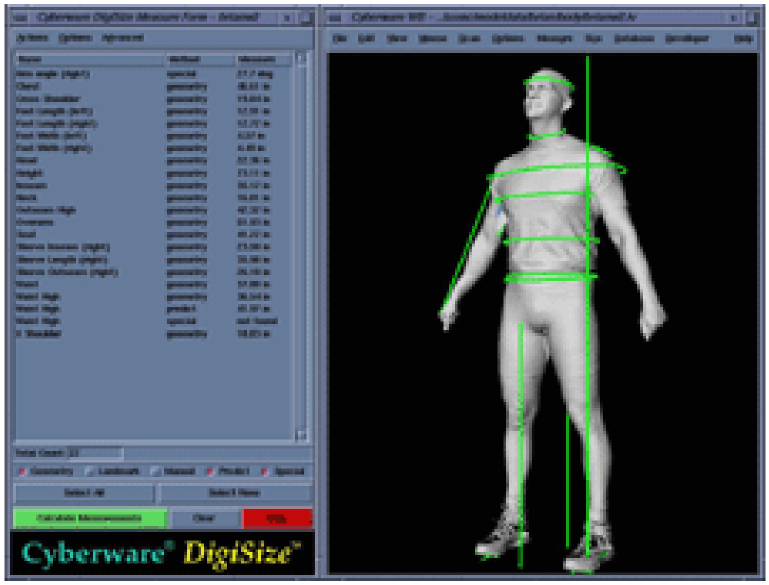

Figure 11. Male VRML image with extracted measurements retrieved from Cyberware, n.d.

Wicks and Wilson Ltd. Wicks and Wilson Ltd. are considered to be world leaders in the development and manufacturing of electronic imaging products. They have developed a 3D body scanner called the Triform Bodyshape Scanner (see figure 12) which has been in the works since the 1990s. The Triform Bodyshape scanner uses the moiré fringe technique to capture the 3D image of the body. This technique uses white light that is shown on the body horizontally to safely and quickly capture the 3D surface of the human body with four cameras. Mirrors are also used during this process to aid in capturing the body in two directions which ultimately produces eight views. Their product takes under 10 seconds to capture the body and under one minute to translate the image into a point cloud rendition that is made up of over 1.5 million points. (Istook & Hwang, 2001; Wicks & Wilson Ltd, n.d.)

Figure 12. Wicks & Wilson Ltd. 3D Triform Bodyshape scanner retrieved from Wicks & Wilson Ltd, n.d.

Telmat Industrie. Telmat Industrie is a developer of IT solutions that serve customers across the globe with products that range from internet security to state of the art body scanners. Their product SYMCAD OptiFit System (see figure 13) is a 3D capturing and automated body measurement system that is used in the development of apparel products namely uniforms and other corporate clothing (Telmat Industrie, n.d.). Telmat's system uses two cameras to capture the 3D replica image of the consumer (Hamit, 2001). They claim that their body scanner is the only one on the market that is capable of acquiring body measurements instantaneously in about 2.5 seconds, which makes subject movement during the scanning process a non-existent problem. Also, the machine is not affected by undergarment color which is not the case for other light based machines such as $[TC]^2$ BMS system. Their product, similar to the other scanners, can be linked to CAD systems for additional used in apparel pattern development. (Telmat Industrie, n.d.) The scanner focuses on 10 key reference points that are used to develop 71 different body measurements. Along with acquiring the information for fit they also offer an added feature of a SYMCAD Body Card which stores the information and measurements retrieved from the body scanner to aid in selecting the perfect fit for a number of retail brands. (Hamit, 2001)

Figure 13. Telmat Industrie's 3D SYMCAD OptiFit system retrieved from Hamit, 2001.

Human Solutions. Human Solutions, formally known as TechMath, is a company based out of Germany that focuses on innovative hardware and software solutions for the measurement and simulation of humans. They have been apart of this field since 1986 and serve mainly the apparel and automotive industries with the aim to get their consumers to interact in the development and manufacturing processes of apparel and automotive products. Three dimensional body scanning makes up a large part of Human Solutions' products and is considered the "flagship" of their company (see figure 14). (Human Solutions, n.d.a.)

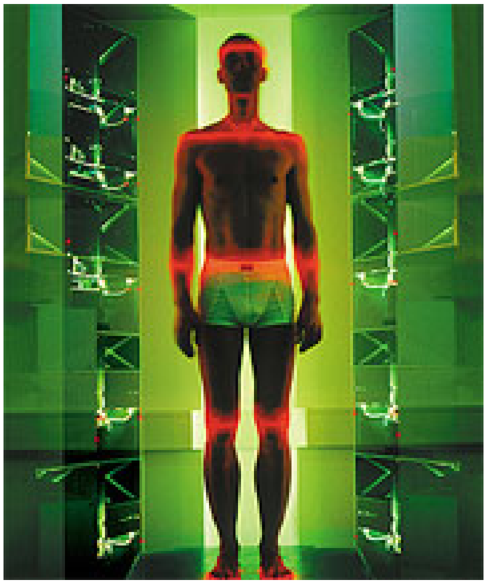

Figure 14. Human Solutions 3D body scanner retrieved from Human Solutions, n.d.a.

Their 3D body scanner uses an eye-safe laser to create an image of the individual in less than 10 seconds. This image can be used in a variety of applications from apparel customization to cosmetic surgery. For apparel, the scanned images can be used to acquire approximately 100 measurements that are entered into their software program RETAILOR (see figure 15) and used to track the consumer's measurements as well as their preferences. This information can ultimately be sent to the manufacturer via the internet (online data transfer), LAN, Email, or fax without middle man involvement. With the use of the 3D body scanner and RETAILOR a company can quickly and economically mass customize apparel to the consumer's needs and wants. Furthermore, because there is no middle man involvement in the process it also illuminates errors that would occur during the middle-stage of product creation. (Human Solutions, n.d.a.)

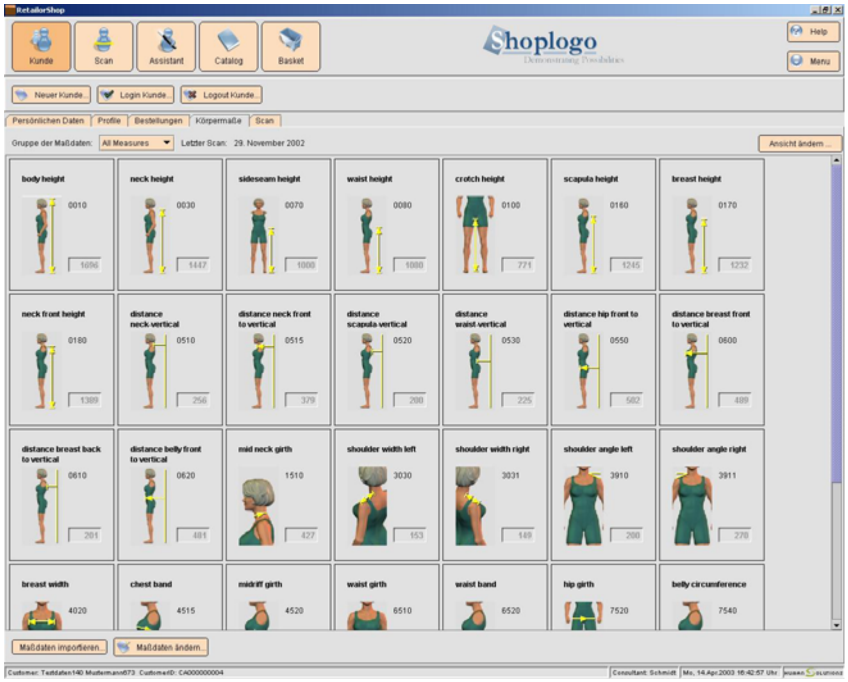

Figure 15. Human Solutions RETAILOR software program retrieved from Human Solutions, n.d.a.

3D Body Scanner Applications

Since their creation, 3D body scanners have been used for a number of activities related and unrelated to the textile and apparel industry ([TC]^2, n.d.b.). Global industries have used these scanners for sizing surveys, development of sizing charts, custom apparel, size recommendations, body shape analysis, animation, graphics, and gaming, health and medical applications, custom mannequins, virtual shopping, and 3D modeling.

Sizing surveys. The first international anthropometric survey to use 3D body scans (Cyberware WB4) was the 1998 – 2000 Civilian American and European Surface Anthropometry Resource Program (CAESAR) by Wright-Patterson Air Force Base. This survey started as a partnership between the government and various industries, including apparel, to collect a large sample of consumer's measurements across the globe. It included 2,400 U.S. and Canadian civilians as well as 2,000 European civilians, both male and female age 18-65 in the study. Each participant was scanned in three positions which included relaxed seating, standing, and full-coverage pose as well as measured using the traditional tape measure method (1D) to acquire an addition 40 measurements. This study served as a model for other anthropometric population studies such as SizeUK and SizeUSA. [TC]^2's SizeUSA survey used the 3D body scanner to enable the creation of appropriate sizing charts and increase the understanding of the human body through different cohorts of the population. This study was comprised of scanned images of over 10,000 women and men across the U.S. (Istook, 2000; Loker, Ashdown, Cowie, & Schoenfelder, 2004 ; [TC]^2, n.d.e.)

Sizing charts. Apparel sizing charts have been developed from 3D scanned images by companies such as Human Solutions. Human Solutions created a software program called ANTHROSCAN (see figure 16) which is used to compile sizing charts based off of a large group of individual's scans. This program quickly and efficiently creates a company's own ready-made size charts and tables. The measurements used to create the sizing charts are taken from user defined locations on the body. Due to the measurements being done digitally, and the images being stored and retrievable, the sizes and tables can be added to and altered at a later date. This process of serial-measuring is considered to be less time-consuming, expensive, labor intensive, and error-prone than the traditional measuring tape method to acquire a sizing system. (Human Solutions, n.d.a.)

Figure 16. Example of ANTHROSCAN 3D body scanning retrieved from Human Solutions, n.d.a.

Custom apparel. Custom fitted apparel applications can be seen implemented in companies such as Brooks Brothers and Benchmark Clothiers where they use the measurements extracted from the 3D scans to customize apparel to fit (see figure 17). (Human Solutions, n.d.a.)

Figure 17. Example of custom made garments retrieved from Human Solutions, n.d.a.

Size recommendations. For consumers who may not purchase customized product but want aid in choosing the best fitted garment for their body measurements and shape, companies offer commercial size recommendation information. In many cases the measurements of the customer are acquired through the use of a 3D body scanning system. For example, Telmat Industrie – OptiFit System SYMCAD Body Card stores the information and measurements retrieved from the 3D body scanner to aid in selecting the perfect fit for an individual in a number of retail brands (Hamit, 2001 ; Loker, Ashdown, Cowie, & Schoenfelder, 2004). Companies such as Hugo Boss introduced their [TC]^2 body scanner to their consumers to aid in selection of apparel products by providing them with sizing information. The consumers that participated in the scanning process were provided a plastic card that indicated the size they need in Hugo Boss products (see figure 18). (Career Threads, n.d.)

HUGO BOSS

J. Brown

	U.S.	U.K.	Continental
Coat/Suit Size	40	39-1/2	50
Shirt	16	16	41
Sleeve	33	33	84
Waist	34	34	86
Inseam	30	30	76
Shoe	9-1/2	8	42

Figure 18. Example of Hugo Boss sizing card retrieved from Career Threads, n.d.

Companies such as FitMe.com have developed software applications that use the measurements extracted from the 3D scans to predict the ideal size of the consumer for hundreds of apparel brands (Loker, Ashdown, Cowie, & Schoenfelder, 2004). In addition, Human Solutions XFIT ARMY system (see figure 19) is a "Clothing Issuing

Planning Process" that is used to select uniforms that will fit a specific individual. This system aids in acquiring the best fit possible from a predetermined selection of off-the-rack choices. (Human Solutions, n.d.d.)

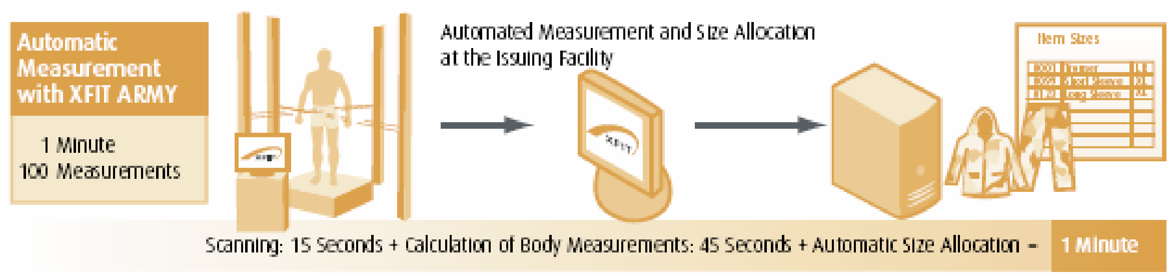

Figure 19. Process of XFIT ARMY technology retrieved from Human Solutions, n.d.d.

Body shape analysis. Body shape can be assessed and analyzed easily with the aid of 3D body scanners. The method of using 3D data to assess body shape has been used in academic and corporate studies to understand the shape of various consumers in the marketplace. (Simmons, 2002) With a better understanding of the shape of the consumer companies can address fit and sizing more accurately (see figure 20).

Figure 20. Example of a true spoon body shape retrieved from Simmons, 2002.

Animation, gaming, and virtual graphics. Three dimensional replica images are used in the creation of animation, virtual graphics, and gamming systems. Companies such as Cyberware use their color scanners to convert the point cloud image into VRML (see figure 21) files which can later be used in web and other digital applications. (Cyberware, n.d.)

Figure 21. Male VRML wearing virtual outfit retrieved from Cyberware, n.d.

Health and medical applications. For companies interested in health and fitness management, shape tracking is an important tool used to inform their consumers on their physical progress while using their services. Three dimensional body scanners have been installed in gyms and other exercise facilities for use at the start of a program to track success and pinpoint changes in physic and body shape over time. (Wicks & Wilson Ltd, n.d.)

Three dimensional body scanners can also be used in various medical applications. One way the scanner is used is in improving image satisfaction and reporting the results of plastic surgery. The system enhances traditional 2D comparative data by showing the consumer the results of their surgery in all dimensions. This allows the consumer the ability to truly see the improvement made and illustrate to the consumer the difference the surgery has made on their lives and self-image (See figure 22). (Human Solutions, n.d.b.)

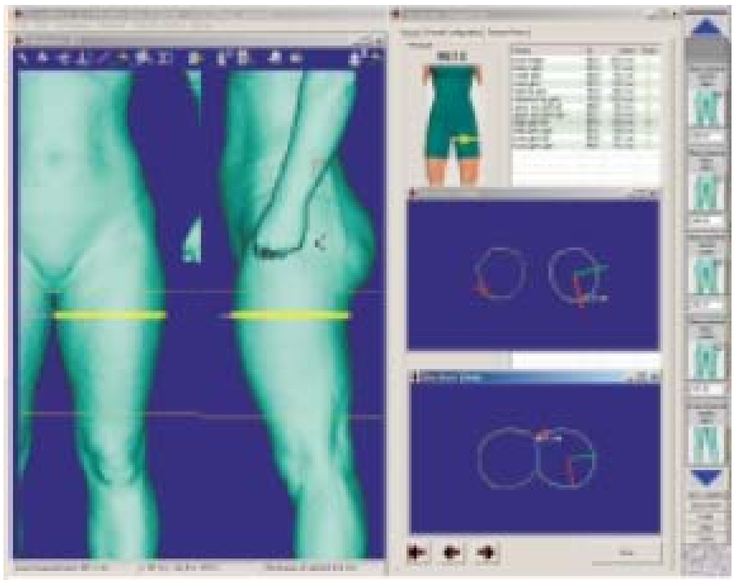

Figure 22. Example of 3D scanner used for plastic surgery retrieved from Human Solutions, n.d.b.

Custom mannequins. 3D body scanners can also be used to help insure standardized fit of garments produced for the same retailer by a number of different manufacturers. Shapely Shadows produces mannequins and dress forms that are duplicates of an individual through the use of the 3D body scanner (Fashion Business, Inc, n.d.). Figure 23 shows an example of 3D produced mannequins. Their products can be used to create mannequins of a fit model to be shipped to numerous companies involved in the product development process to ensure consistent and standardized fitting and sizing of off-the-rack apparel irregardless of where the supplier is located. (Human Solutions, n.d.a.)

Figure 23. Mannequin developed from 3D body scan retrieved from Human Solutions, n.d.c.

Virtual 3D modeling. Virtual shopping and 3D modeling is also an innovative method of using 3D replica images created by the 3D body scanner. Cyberware's color 3D body scanner creates individual duplicate image that can be converted and used as vessels for trying on garments digitally. (Cyberware, n.d.) Wicks & Wilson also use their scanners for visualization of "photo-realistic" clothing that can be used in retail store or over the internet. (Wicks & Wilson, n.d.)

Benefits to Using 3D Body Scanners

The CAESAR anthropometric survey claims that their use of the 3D scanner derived information that is of immense benefit to the industry. They claim that because of the use of the 3D body scanner in their anthropometric survey, the information derived is better due to 1) the reduction in inaccurate body measurements, 2) the allowance for numerous measurement extractions, 3) the proper visualization of subject to reduce design issues, 4) providing enough data to choose accurate measurements for a sample population, and 5) providing raw data for user interpretation (Istook & Hwang, 2000; SAE International, n.d.). Other rationale for the implementation of the 3D body scanner in the apparel industry for mass customization are 1) it is a faster process than the traditional measuring tape method, 2) it is a contact-free measurement process, 3) it is an objective measuring process, 4) the user has control over measurement location and quantity, 5) it gives the consumer a radically new purchasing experience, and 6) it is a means to lure consumers to the company. (Human Solutions, n.d.; Istook & Hwang, 2000)

Overall, the use of the 3D scanner can aid not only in product development but also in increasing consumer satisfaction and enjoyment. This is because the use of the 3D body scanner forces the consumer to involve themselves in additional interactions with the company to achieve the product they want. Many consumers value the experience and input provided through this process. A study conducted by Cornell University found that participants were excited about the potential uses of the 3D body scanner, especially in its commercial applications (Loker, Ashdown, Cowie, & Schoenfelder, 2004). Therefore, product value can be derived not only from the unique product but also the unique experience the 3D body scanner provides. (Fiore, Lee, & Kunz, 2003)

Mass Customization

Historically, all apparel was custom because it was produced completely by hand either in the home or by professional tailors. In this time all patterns were created by draping or pattern drafting from an individual’s measurements (Standardization of Women’s Clothing, n.d.a.). This era in apparel production is usually referred to as the craft production era because each garment was an individually customized piece of art. However, in the early Twentieth Century with the onset of the industrial revolution and a growing middle class, a way for affordable, fashionable, ready-made clothing was forged (Keiser, & Garner, 2003). The factories that produced ready made clothing were drastically changed with the inception of pattern design systems which have been in place since the early 1980s (Burns, & Bryant, 1997). This and other technology has lead to a cycle of change from mass production back to the revival of custom products in the form of mass customized apparel.

In order for dimensional mass customization to be realized today, companies must implement unique operational processes. These processes and technologies are needed in order to 1) interact with the consumer to obtain specific information, 2) create the product to consumer's individual specifications, and 3) track the product to insure proper completion and correct delivery (Zipkin, 2001). Having a way to interact with the consumer is very important when it comes to apparel and creating a garment to specific measurements. It is also important to allow the consumer ease in selecting and giving information about what they want in the product they are purchasing.

Companies approach accomplishing the first component needed for mass customization, acquiring information from the consumer, differently. The most wide-spread way to obtain the measurements needed to dimensionally customize a garment is to take the measurements of the consumer using a tape measure and send the information about the garments construction, color, fit, fabrication, and style to the manufacturing plant via the World Wide Web (Glock & Kunz, 2005). The tape measure method can be done by measuring consumers face to face or asking consumers to supply their own information via the web (Corcoran, 2005). However accomplished, the process of manually measuring the body is time consuming, invasive, and often inaccurate. The manual measurements taken by one person may be inaccurate and inconsistent with another persons measurements of the same individual even if trained to do it a specific way (Glock & Kunz, 2005; Istook, 2000). This inaccuracy is made further evident by the 1988 anthropometric survey conducted by the US Army in which researchers needed four hours to "…physically landmark, measure, and record the data of one subject" (Istook & Hwang, 2001, p. 120). This potential lack of consistency in measurement can result in garments not fitting the same even if the garments are made for the same ultimate consumer (Glock & Kunz, 2005). Two other approaches companies use to obtaining body measurements are having consumers try on sample garments, or using scanning technology to acquire information (Corcoran, 2005). Using three-dimensional body scanners to obtain accurate body measurements is an innovative change to the former. This technology delivers "…an unlimited number of measurements of human bodies in the matter of seconds because an image of the body is captured during the scanning process…" (Hwang, 2004, p. 2-3). The measurements obtained through this process are acquired faster and are more accurate, precise, and reproducible than the measuring tape method explained earlier.

Approaches to the second step of mass customization, creating the product to the consumer's individual specifications, also vary from company to company. For many companies, once the information is received users can adjust patterns either manually or automatically. However, pattern adjustments may be very time consuming especially when producing Made-to-Measure garments on a large scale (Glock & Kunz, 2005).

This is especially true when manufacturers have to take the measurements and manually key them into a size code table. The information entered into the size code table is used manually to create the pattern, which is ultimately a tedious, time consuming, and complicated method of creating a Made-to-Measure garment because of the high level of user involvement (Hwang, 2004; Istook, 2002). Some programs available on the market allow the user to utilize the information entered into the size code table to automatically change the pattern to the consumer's measurements.

In order to carry out the process of manually or automatically altering a basic pattern to meet the dimensional specifications of the consumer there are a number of steps that must first be set up in the background of the program. The rule table for grading in combination with a basic size code table is used to find the closest fitting size to the individual consumer. The use of the graded block that is closest to the measurements of the consumer decreases the need for numerous changes to be made to the pattern. It also decreases the likelihood of creating a garment that is not shaped appropriately. After the closest grade is chosen, the measurements of the consumer are used to create a customized size code table that will be used during the alteration process. Lastly, the Made-to-Measure (MTM) system mergers the consumers size code table, graded alteration rule table, and the basic pattern together to create a custom fit garment. (Istook, 2002)

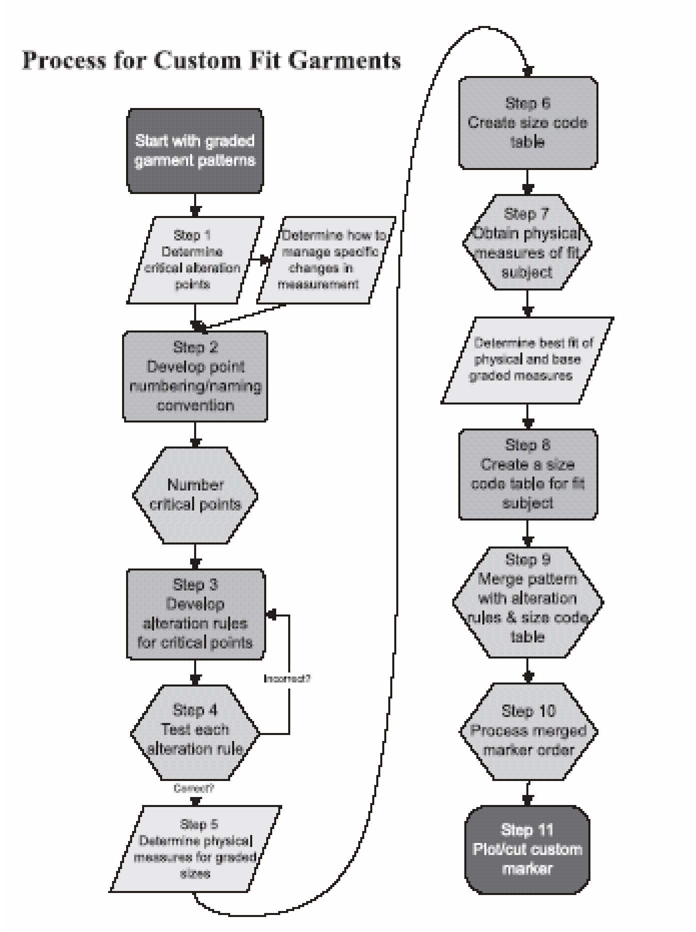

Figure 24. Istook (2002) figure of the pattern alteration process in typical CAD program

Made-to-Measure Industry Leaders

Lectra Systems, Inc.

Lectra Systems, Inc. is one of the industry leaders for CAD/CAM systems that are used in apparel product development. They have over 17,000 customers and 1,500 employees worldwide. In 2005, 60% of their revenue in sales was from the fashion and apparel market and 34% of their sales were from CAD/CAM systems. Along with providing product for the apparel sector, Lectra also provides technology for the furniture, automotive, aeronautical, and marine industries. (Lectra Systems, Inc., n.d.a.)

Lectra's apparel CAD system offers the capability to produce Made-to-Measure products from 3D body scanned images. Their exclusive partnership is with the manufacturer Human Solutions, which is the world leader in body measurement and 3D human body imaging. Lectra believes that their innovative technology will open up apparel customization opportunities for not only small specialty retailers but also large apparel producers such as uniform manufacturers. (Lectra Systems, Inc., n.d.f.)

In 2000, at the Bobbin Americas Show in Atlanta Georgia, Lectra demonstrated their new FitNet customization software (see figure 25) that integrated 3D scanned measurements with pattern making CAD systems (Hwang, 2004). This system is the bases of Lectra's mass customization technology. It allows companies to create a database of options such as fabrics and colors for styles that they offer. These options can be displayed on a style screen and used at the point-of-sale by the ultimate consumer to aid in product development. The consumer is then able to select different combinations of options all the way down to buttons and/or monogramming. (Lectra Systems, Inc., n.d.d.)

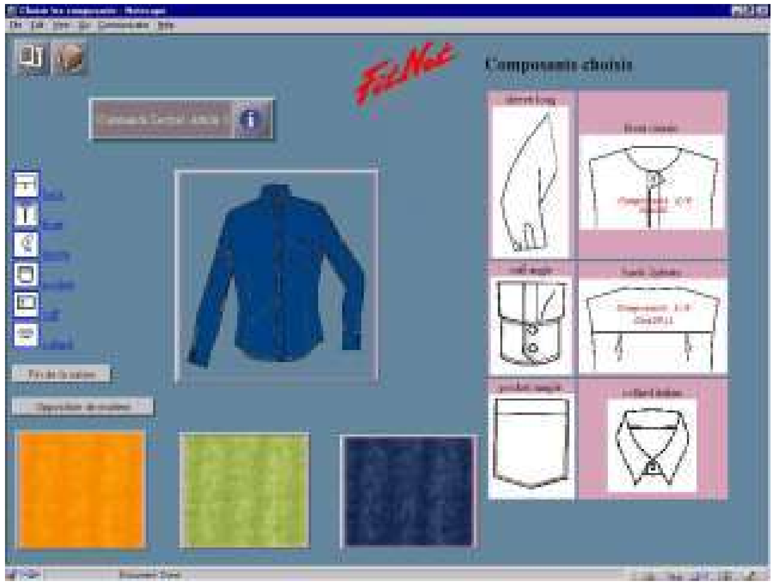

Figure 25. Lectra's FitNet system retrieved from Lectra Systems, Inc., n.d.e.

After the consumer has determined the styling of the garment it is then sent via the internet to the manufacturer's plant (Lectra Systems, Inc., n.d.h.). Once sent, Lectra's ScanWorx extracts the measurements of the individual from the 3D scan based on predetermined parameters. Modaris software pack (see figure 26) MODEPRO then automatically compares these measurements to measurements of a base size where it, without any human intervention and within minutes, alters the patterns normal grade to fit the consumer perfectly. It also pairs up the consumer's preferences for fabric and other options with the custom pattern to be sent to the cutting system (Lectra Systems, Inc., n.d.b.; Lectra Systems, Inc., n.d.h.). According to Lectra, the customization software MODEPRO is extremely versatile and can fit easily within a mass production company. (Lectra Systems, Inc., n.d.b.)

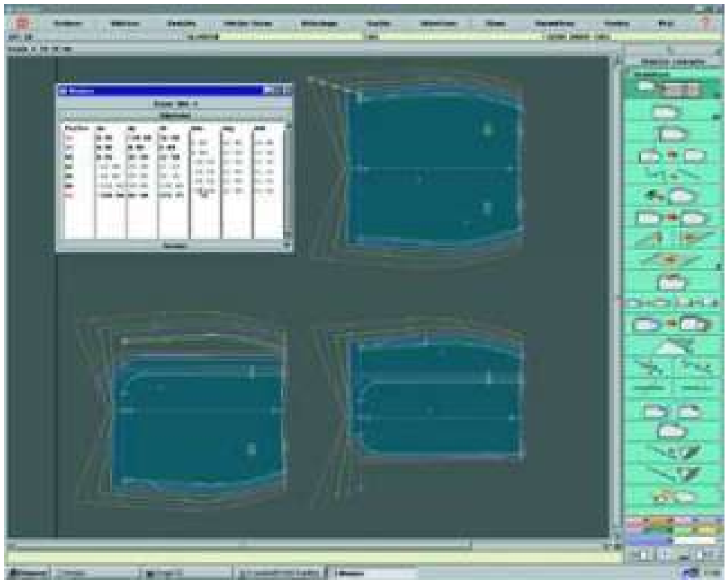

Figure 26. Lectra's Modaris system retrieved from Lectra Systems, Inc., n.d.g.

A second software system that works with the Modaris and FitNet is the Modaris Expert. Modaris Expert can be used to automatically transfer alterations and grading to pieces other than the main shell fabric, i.e. linings and facings. It is also used to check for consistency of measurements (truing) in a matter of minutes. (Lectra Systems, Inc., n.d.b.)

OptiTex USA

OptiTex is a developer of CAD/CAM systems specializing in 3D and 2D fashion design software. Their product, called OptiTex pattern design software, can be used along side of a digitizer to input information into the program to be altered and stored for quick access and alteration. The software also allows the user to develop new patterns manually on the computer as well as alter the patterns that were digitized and stored (OptiTex, n.d.c.). OptiTex has also developed software geared toward the Made-to-Measure arena of apparel product development. OptiTex Modulate (see figure 27) is a "…interactive, parametric, one of a kind, Made-to-Measure software engine" that can be used to alter the dimension of particular areas of a pattern to fit a consumer or company fit model. Each adjustment made can be named and saved in a "variable library" for future use. This library allows for repeat orders to quickly be processed. (OptiTex, n.d.d.)

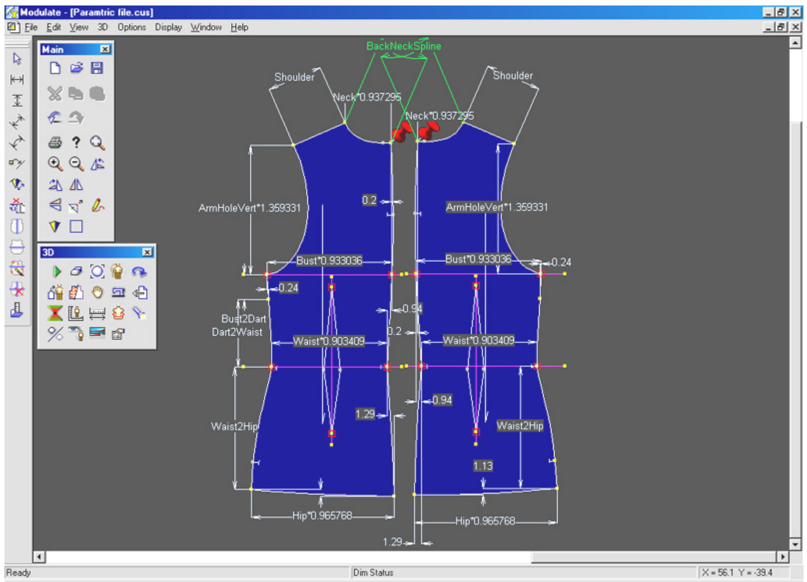

Figure 27. OptiTex Modulate retrieved from OptiTex, n.d.d.

Two-dimensional to three-dimensional pattern making. Another software program created by OptiTex is OptiTex runway creator for PDS (see figure 28). This system integrates 2D apparel design with 3D virtual garment display. This allows the user to create a garment in the PDS system, as a flat 2D pattern, and drape the garment created onto a 3D virtual runway model. This ultimately allows the user the ability to see the "prototype" garment on the "body" virtually which can aid in quicker assessment of fit and style before moving onto time consuming, tangible apparel product development. (Loker, Ashdown, Cowie, & Schoenfelder, 2004; OptiTex, n.d.b.)

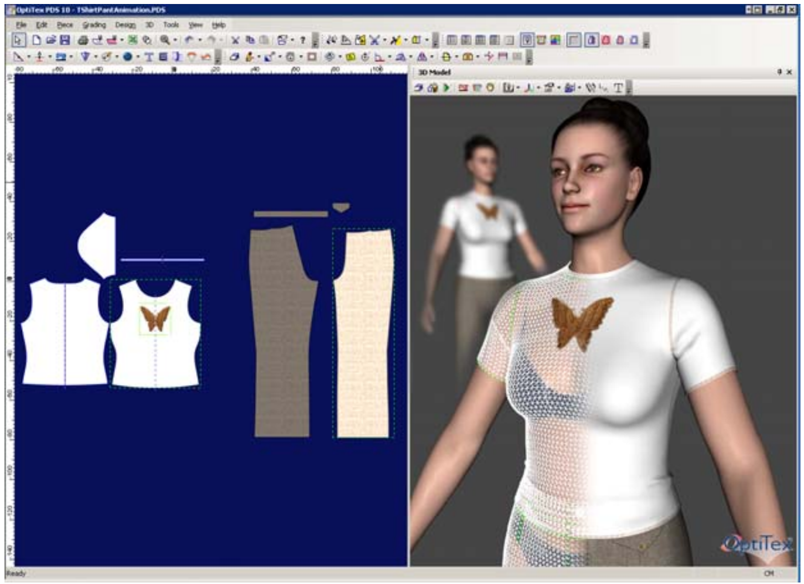

Figure 28. OptiTex Runway Creator for PDS retrieved from OptiTex, n.d.b.

OptiTex also offers the option to check the fit of a particular garment as it relates to an individual's measurements. OptiTex Runway Creator for Modulate (see figure 29) offers the user the ability to alter a virtual model's body measurements in 40 different locations. Once the image is changed into a "virtual twin" of the consumer, the user can virtually drape the 2D pattern on the "twin's" body to check for fit in several different stances and posture positions. (OptiTex, n.d.a.)

Figure 29. OptiTex Runway Creator for Modulate retrieved from OptiTex, n.d.a.

Gerber Technology, Inc.

Gerber Technology Incorporated is another major CAD producer for the apparel industry. Their software program AccuMark is considered to be the apparel industry's standard software program for pattern design, grading, and marker making. Along with this, Gerber Technology is also the creator of standard software programs for other industries, such as transportation interiors, furniture, and industrial fabrics industries. (Gerber Technology, n.d.a.)

For apparel, AccuMark contains the most comprehensive grading and seam allowance tools offered on the market. They provide both hardware and software systems that are used in thousands of companies and in more than twenty languages. Similar to Lectra Systems, Inc., Gerber has developed a mass customization CAD system called AccuMark Made-to-Measure (MTM). AccuMark MTM automatically alters a basic model (garment) according to the consumer's style choices and measurements. The measurements can be either manually entered or automatically entered via the 3D body scanner. Gerber also offers a product called 3D Direct, which is a program that is used to flatten a 3D image of an object into a 2D pattern. This feature can be used in the AccuMark system and is claimed to take days out of the product development cycle mainly because it minimizes the need to make numerous prototypes to fit the object correctly. Overall, 3D Direct is predominantly being used in automotive design. (Anderson, 2005)

Gerber Technology feels that these software programs will reduce the time it takes for a company's custom products to reach the ultimate consumer. This is due to the automation in selecting and making decisions on pattern alteration as well as the ability for the software to connect with other automated systems already in place such as AccuNest or NESTERserver. With implementation of the entire package of programs simply one button will start and complete the process from pattern alteration to garment cut. (Gerber Technology, n.d.b.)

Importance of New Technology

Implementing new and innovative technology is a way that a company can increase and/or keep their competitive advantage. In order for a company to attract the consumer and ultimately survive they must have a way to lure the consumer to them in hopes that they will purchase their product over their competitions. Once consumers have been persuaded, then that company has established and must continue to maintain their competitive advantage over the competition. A company is considered to have established a competitive advantage when they have kept a steady increase in profits that are higher than the industry average. Therefore, reaching the point of being classified as having a competitive advantage is a goal that most companies try to achieve. (Quick MBA, n.d.)

According to Michael Porter there are two main sources of competitive advantage. These two sources are cost leadership advantage and product differentiation advantage. Cost leadership creates competitive advantage by offering the value of low cost. However, for product differentiation, the value is derived from the product being perceived by the consumer as unique (Keegan, 2002). For both forms of competitive advantage a company must have the means to create the advantage through the use of superior resources and capabilities. Resources are considered to be assets useful for creating cost or differentiation advantage. To be classified as a resource the asset can only be available to a few companies or hard to acquire. Capabilities are the company's ability to utilize its resources effectively. When a company invests in resources such as new technologies they are doing so to acquire, maintain, or increase their competitive advantage. When these companies technologically upgrade their systems' capabilities or introduce new machinery, they can now offer new products, and/or faster, lower-cost methods of production (Asian Development Outlook 2003, n.d.). However, if the resources and/or capabilities the company is using to gain its competitive advantage are easy for other firms to adopt and use, their advantage will be diluted and quickly become non-existent. Therefore, a company's unique resources and capabilities are the factors that enable them to achieve competitive advantage via cost leadership or product differentiation (Quick MBA, n.d.). For apparel producers, mass customization technology is a way to differentiate themselves from other companies. With the new resource of the 3D body scanner and 3D to 2D automatic pattern unwrapping systems, companies will have a resource that will give them an edge over other mass customization companies.

3D to 2D Automatic Pattern Unwrapping

Three-dimensional to two-dimensional automatic pattern unwrapping is $[TC]^2$ newest software development system. This feature became available with the new NX-12 scanning system which was launched in 2004. The software allows the user to define a garment on a 3D body image that was extracted from a 3D body scanner ($[TC]^2$, 2004). It has the unique ability to automatically extract a custom pattern of garment blocks/slopers and finished patterns without using measurements, but instead direct 3D to 2D data conversion. Design features like pleats and darts are pre-defined, along with fit and ease parameters ($[TC]^2$, n.d.a.). The 3D garment defined can be automatically flatted into a 2D pattern in the Drawing Interchange File (DXF) format and then can be imported to a CAD system such as Gerber AccuMark PDS ($[TC]^2$, 2004). Unlike traditional pattern development that only accommodates one shape of the body and changes measurements according to that one shape, this system allows for the individual's body shape to be considered as well as their measurements (Apparel Sourcing Show, n.d.).

Chapter 3: METHODOLOGY

Research Purpose

This research will focus on 1) increasing the knowledge about the 3D to 2D pattern unwrapping software, 2) determining how well the system works for various body shapes and sizes, and 3) gaining knowledge of the consumer's reaction to the process and fit of the 3D to 2D garments.

Research Objectives

1. To create an evaluation tool that can be used to assess the fit and appearance of garments.
2. To determine the participants current fit issues with off-the-rack apparel products.
3. To determine participant reaction to the 3D body scanning process.
4. To identify the process that will enable 3D to 2D patterns to be used for garment design.
5. To determine how all participants' 3D to 2D patterns should be changed to be in accordance with the evaluation tool.
6. To determine how groups of participants' 3D to 2D patterns should be changed to be in accordance with the evaluation tool.
7. To determine how participants rate the fit of the garment made from the 3D to 2D system.

Data Collection

Garment Evaluation Tool

Evaluation of garment fit is an extremely subjective process. In order to eliminate variance a rubric was developed from the literature collected on garment fit and appearance in chapter two. This information was used to strategically assess the major aspects of each garments fit and appearance. The rubric was separated into three parts. Each of these parts was used to evaluate one of the three garments, either bodice, skirt, or pant. In order to evaluate these garments key fit and appearance variables determined by the literature were evaluated. The variables determined through the literature (Editors of Creative Publishing International, 1987; Handford, 2003; Joseph-Armstrong, 2006; Shepherd, 1997) to impact fit were seam length, seam uptake, seam level, dart uptake, number of darts, gaping, and crotch rise. The variables taken from the literature (Editors of Creative Publishing International, 1987; Handford, 2003; Joseph-Armstrong, 2006; Shepherd, 1997) that impacted the garments appearance were seam position, seam angle, dart length, dart leg position, and dart apex position.

This information was entered into a rubric in which each fit and appearance variable mentioned above was assigned to each garment where applicable. For example, the bodice side seam was determined to involve the fit variables of seam length, and seam uptake, and involve the appearance variables of seam position, and seam angle. Once each garment's fit and appearance variables were determined the ideal fit and appearance of these areas were determined through the literature and entered into the rubric. For example, the side seams position and angle's 'ideal fit' description is "should be perpendicular to the floor". The last area of the rubric was the problem column. This was used to manually write in the issues that were found in the garment being assessed.

Initial Sample Selection

The initial sample of 28 participants was obtained via convenience sampling methods. They consisted of women who were located primarily in North Carolina. There were a number of ways that the convenience sample was selected. The primary way of selection was through recruitment of students who attended North Carolina State University's College of Textiles. They were recruited from both undergraduate and graduate level classes that were offered through the College of Textiles. Other methods were word of mouth recruitment which spread to other universities in the area such as North Carolina Central University, Duke University, and East Carolina. In all cases of recruitment, there were no incentives offered to the students and other participants. Upon completion of scanning, participants were given a print out of their measurements along with a scanned image of themselves.

Initial 3D Body Scanning Process

The [TC]^2 body scanner was used in this study because of accessibility to the university as well as its proximity to the supplier. Furthermore, this scanner was found to produce consistent and accurate body measurements, within an average of 0.35 inches, (Mckinnon & Istook, 2002). There were a number of steps that a participant went through to acquire a useful scanned image for the study. Each participant was first given a short tour of the [TC]^2 3D Body Scanner. The tour consists of showing what apparel the participant could wear, where they could get unclothed and dressed privately, how the participant should stand once in proper attire, and how the participant would start the body measurement process. During the tour time, the purpose of the study and method of maintaining confidentiality were explained. After the tour each participant was required to follow a number of steps. These steps included:

1. The participant filled out and signed a confidentiality form that consisted of contact information, demographic information, and confidentiality number.
2. The participant's height and weight was taken and documented on the form along with their scanning number which was used as a replacement of the participants name for confidentiality purposes.
3. The participant entered the scanner and proceeded back to the dressing room where they were to put on supplied garments. The supplied garments were required to properly fit so as not to constrict the body nor be too loose on the body.
4. The participant removed all jewelry, accessories, and other miscellaneous adornment as well as put their hair up off of their neck, if necessary.
5. Once dressed the participant stepped into the closed scanner and placed their feet in the predetermined location that was signified by the marking footprints.
6. The participant held onto the side rail bars located next to each hand in a relaxed pose.
7. Once participant was standing completely erect with arms relaxed, the participant pressed the button located next to the right thumb on the hand bars to activate the machine and begin the 3D body measurement process.

8. Once the scanning process was completed the participant stood and waited for confirmation that the scanning process was a success. If the scan was not of “good” quality steps 5-8 are repeated until a “good” image was collected.
9. Once the confirmation had been relayed, the participant stepped back into the dressing room and put back on their street clothing.
10. The participant’s image was used to extract 3D measurements of the body and the 3D body image was saved in the computer in .RBD, .ORD, .VRML and .BIN file formats.
11. Upon completion the participant was given their 3D body scan and measurements.

Final Sample Selection

From the 28 participants that were scanned in the initial sample, 10 were kept to be used as the final sample for the study. The final sample was selected by visually assessing the participant’s body shape and size. A variety of body shapes and sizes were needed to evaluate the accuracy of the 3D pattern unwrapping software as it relates to creating a “good” fitting garment across various consumer body dimensions and figures. The body shapes were determined through visual assessment while the sizes were assessed through the measurements extracted from the participant’s 3D body scan. Ultimately, the participants were categorized by Body Mass Index (BMI), height, weight, bust measurement, waist measurement, and hip measurement.

3D to 2D Pattern Unwrapping Process

The study’s primary objective was to analyze the fit of the patterns of a bodice, skirt, and pant that were produced using $[TC]^2$’s NX-12 pattern unwrapping software program. There were a number of steps that had to be taken to convert the 3D scanned images into 2D basic patterns of each participant. However, before these steps could take place the initial setting up of the preferences that tell the software how to extract the 2D pattern from the participant virtual image was decided upon for each garment. These parameters were consistent for each garment type to ensure there was no variability in how the garments were extracted from the 3D scanned images. The major parameters of each step are listed below.

Extraction Parameters

Each garments extraction is controlled by a set of variables or extraction rules called parameters. The entire set of parameters is called a measurement extraction profile (MEP). These parameters tell the computer how and where the garment should be extracted from the scanned image. The parameters for each garment were defined by choosing from the list of options available. Appendix A provides the parameters and extraction profiles created for the bodice, skirt, and pant patterns. For the case of this study the parameters set to dictate the extraction of the bodice, skirt, and pant were as follows.

Waist circumference. The waist circumference for the purpose of this study and to go along with the literature review was defined to be extracted parallel with the floor. The parameter was set to extract the waist measurement as the smallest circumference between the bust and the hip that was .5 inches from the small of the back. The full waist, front waist, and back waist measurements were all included in the bodice extraction profile. The full and right waist heights were the measurements used in the skirt extraction profile and the full waist measurement was used for the pant extraction profile.

Neck to waist length. The neck to waist length measurement was defined to be perpendicular to the floor and not contouring to the body underneath but rather going over the bust as if the participant was wearing a sports bra. Both the back and front neck to waist measurements were used in the bodice extraction profile. This measurement started from the base of neck and followed down the body vertically to the prior defined waist circumference measurement location.

Shoulder length. This parameter was set to be measured from the base of the neck to the end of the shoulder. Both the right and left shoulder length measurement were extracted at a 10/100 slope from the armpits for the bodice extraction profile.

Chest circumference. This measurement parameter was set to be taken at the middle of the armpit parallel to the floor. It was set to just encompass the chest and not to measure over the shoulders. The front and back bust circumference parameters were both extracted for the bodice extraction profile.

Sleeve length. The sleeve measurement was extracted from the back neck point over the shoulder ending at the wrist. Only the maximum length for a shirt sleeve measurement was extracted for the bodice extraction profile.

Armhole height. Both the back and front average armhole height parameters were set and used in the bodice extraction profile.

Bust circumference. The parameters of full bust, front bust, back bust, and bust to bust measurements were used in the bodice extraction profile. These measurements were all taken parallel to the floor.

Abdomen circumference. The abdomen circumference measurement was taken parallel to the floor. The full abdomen was the parameter used in both the skirt and pant extraction profiles.

Hip circumference. The hip circumference was defined as the largest circumference between the waist and the crotch. This measurement was taken parallel to the floor. For the skirt and pant extraction profiles the full hip measurement was defined.

Seat circumference. The full seat circumference was the parameter used in the skirt and pant extraction profile. The measurement for the seat was taken parallel to the floor.

Calf height. The left calf height was the parameter measurement used for the skirt extraction profile.

Dart. The dart parameter was set to produce at least one dart for the pant extraction. The maximum and minimum each dart could be was 1.5 and 0.75 inches wide respectively. The minimum length of each dart was set to be 3 inches for the front and 5 inches long for the back, while the maximum length was set to be 4 inches in the front and 8 inches in the back. The first dart for front and back was determined to be placed half way between the center of the body and the side seam.

Pleats, waistband, and leg shaping. The pleats parameter was set to not include any pleats for the pant extraction profile. Similar to the pleats parameter the pant extraction profile omitted a waistband. The pant extraction profile was also determined to not include leg shaping at neither the knee nor the thigh.

Extraction Profiles

Bodice extraction profile. After the main parameters for each measurement had been set, the parameters that dictated the overall garment, such as ease and seam allowance, were selected to match the literature collected on fit of a basic pattern with traditional ease. In the case of the bodice ease, the software system predetermined the ease and therefore it could not be changed. However, ease of the sleeve could be altered. The ease at the sleeve hem was set to be 1 inch and the ease of the sleeve cap was set to be 1.25 inches. The final Measurement Extraction Profile (.MEP) for the bodice was made up of the combination of choices that were decided upon in each measurement and parameter set. Each of the items listed in the Output Order box showed up on the body and was used to create the final 2D pattern. This .MEP file was saved as CDSBodice.mep. Ultimately, every participant used the same .MEP file to extract their bodice.

Skirt extraction profile. After the main parameters for each measurement had been set, the parameters that dictated the overall garment such as ease and seam allowance were selected to match the literature collected on fit of a basic pattern with traditional ease. For the skirt the ease for the waist was set at 1 inch and the hip was set at 3 inches. The final .MEP file for the skirt was made up of the combination of choices that were decided upon in each measurement and parameter set. Each of the items listed in the Output Order box showed up on the virtual body during extraction and was used to create the final 2D pattern. This .MEP file was saved as CDSskirt.mep and used for each participant's skirt pattern extraction.

Pant extraction profile. After the main parameters for each measurement had been set, the parameters that dictated the overall garment such as ease and seam allowance were selected to match the literature collected on fit of a basic pattern with traditional ease. For the pant, ease at the waist was set at 1 inch and the hip was set at 3 inches. The circumference of the hem was also selected to be 19 inches. The final .MEP file for the pant was made up of the combination of choices that were decided upon in each measurement and parameter set. Each of the items listed in the Output Order box showed up on the virtual body and was used to create the final 2D pattern. This .MEP file was saved as CDSpantsnopleat.mep and used for every participant's pant extract.

Garment Extraction

After each set of garment parameters was in place each garment was extracted one at a time. The garment was extracted to form a .DXF file. This file type allowed the extracted garment to be used in the pattern design program (PDS). For this study the PDS system that was used was Gerber AccuMark Patternmaker. This is because it is one of the major PDS systems available in the apparel industry as well as to the North Carolina State University campus.

To start the garment extraction process, the digital reduced body data (.RBD) image of the participant was first opened. After the image was loaded on the screen the extraction (see figure 30) of the chosen .MEP file was made, i.e. CDSBodice.mep. This automatically created both an .ORD and .DXF file under the folder named Orders.

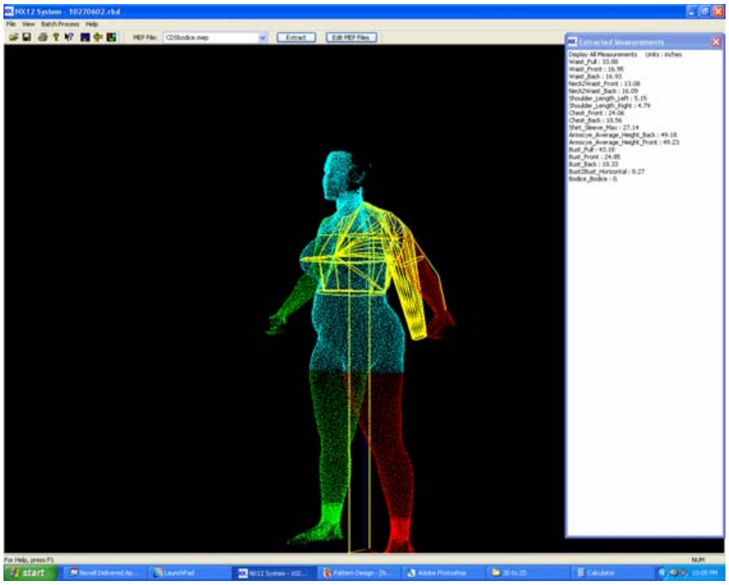

Figure 30. Image of bodice extraction.

To get the patterns into the Gerber AccuMark PDS system the previously created .DXF file was opened. This automatically brought up the pattern pieces created from the scanned image into the piece bar (see figure 31). The pattern pieces were then saved with the participant's ID number before each pattern piece, i.e. 10270601BODFT.

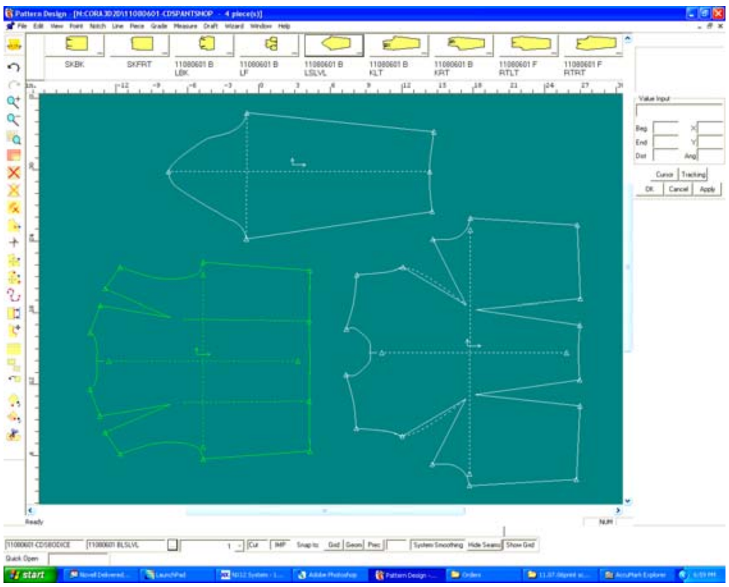

Figure 31. Image of 2D pattern in Gerber AccuMark patternmaker.

A model was made to store all the pattern pieces for each garment for each participant. The model was named after the participant's ID number, i.e. 10270601. Once a marker was made of the garments, the pattern pieces were cut out of muslin on the automatic single ply Gerber cutting table. The pattern was cut with no seam allowance at the neck, armhole, waist, and hem, and with ½ inch seam allowance at the side seams, center back, and shoulder seams for garment construction (see figure 32).

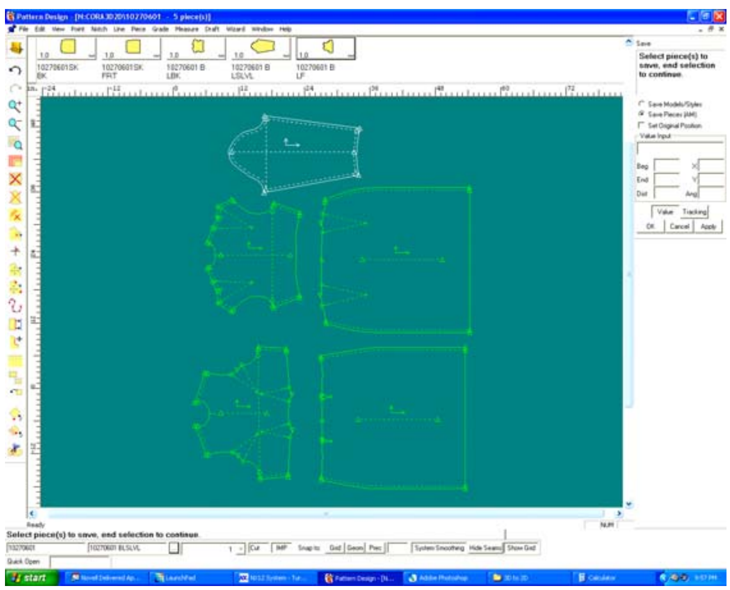

Figure 32. Seam allowance added to 2D pattern for cutting.

Each garment was made out of muslin fabric. For this study a coarse-weave unbleached version of muslin fabric was used because, according to the literature, this fabric is the ideal fabric to use in testing basic patterns. The patterns were cut on the straight grain otherwise known as the lengthwise grain or warp grain. The use of this grain line was decided because it is the ideal grain line to use in pattern development as well as because the lengthwise grain is more stable and has a lower likelihood of yielding to tension put on the fabric when the body is underneath. Once cut, the pieces were again labeled the same way as its digital counterpart piece for tracking purposes. The garments were sewn together using a machine baste stitch to make it easy to take out seams and stitches for adjustment if necessary. After these steps were completed the garment was ready for the fit and appearance assessment process. (Joseph-Armstrong, 2006)

Final Garment Selection

The garments that were used in the study to evaluate fit were the garments that were generated by the NX-12 system that imported into the PDS with recognizable pattern pieces. For example garments that imported into Gerber AccuMark with one point astray were used. However, garments that were imported with many points astray and therefore produced an unrecognizable pattern piece were not used. The selection of the pattern pieces to test was at the discretion of the administrator. Ultimately, from the 10 final participants, there were 7 skirts, 7 pants, and 8 bodices that were evaluated in this study. (See figure 33).

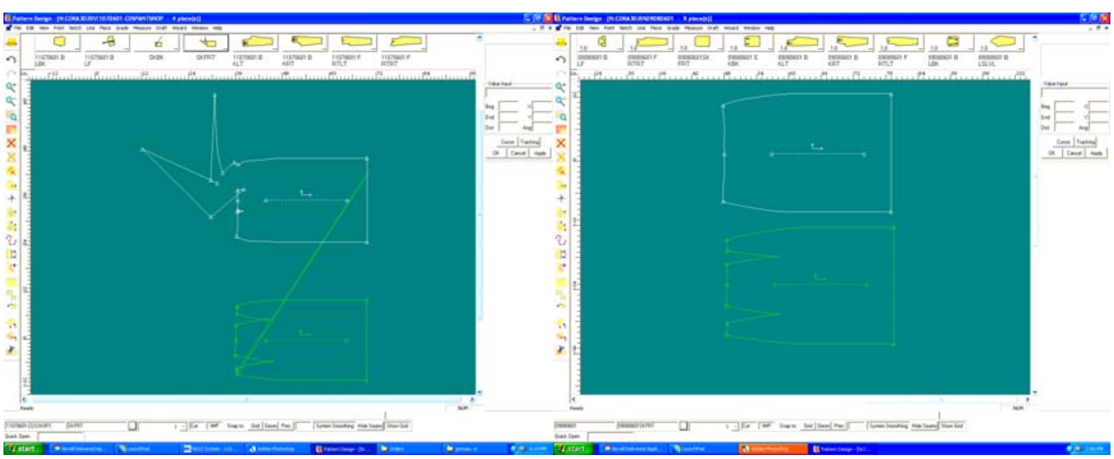

Figure 33. Unusable skirt pattern Vs. usable skirt pattern.

Fit Session of 2D Pattern

The fit sessions were done in the same manner for each participant so as to eliminate variation. Each participant was fit in the 3D to 2D garments that were produced, starting with the participant wearing the bodice and skirt together and then wearing the pant. If there was not a skirt created the bodice and pant would be worn together, and if only one garment was produced then it was worn alone. The first garment assessed was the bodice, then the skirt, and lastly the pant. Initial photos of the garments on the participant's bodies were taken to show the initial fit of the 3D to 2D garment produced. (See figure 34).

Figure 34. Image of initial fit of 3D to 2D pant pattern.

Once the photo was taken, all of the muslin garments are assessed for proper fit according to the garment evaluation rubric created to fulfill objective one of the research. Each of the garments was assessed from top to bottom. The changes were made from top to bottom because adjustments made to the top of the garment affect the fit of the bottom of the garment (Shepherd, 1995). If changes were needed to the seams or other areas the basted stitches were removed and the changes were pinned and marked to adjust the muslin pattern (Joseph-Armstrong, 2006). All of the changes made to the garments were kept on record in photo format (see figure 35) as well as in the garment evaluation tool (see table 3). (Shepherd, 1995)

Figure 35. Image of alternations needed for 3D to 2D pant pattern.

Table 3. Sample pant garment evaluation tool with changes marked.

Pant Fit Assesment											
III: Appearance											
Seams											
Fitting Area	**Item**	**Problem**	**Corrections Made**								
				Back	**Back Neck Point**	**Back Armseye Point**	**Back Waist Point**	**Front**	**Front Neck Point**	**Front Armseye Point**	**Front Waist Point**
Leg Side Seams	Pant Side Seam Uptake										
	Pant side Seam Position										
	Pant side Seam Angle	too far from center front at waist		+2				-2			
Waist Seam Level	Pant waist seam level										
Center Back Seam	Center Back Seam Uptake										
Crotch Seam	Crotch Seam Rise/ Length										
Darts											
Fitting Area	**Item**	**Problem**	**Corrections Made**								
Front Pant Darts	Center Front Pant Dart Uptake										
	Side Seam Front Pant Dart Uptake										
	Front Pant Dart Position (dart legs)										
	Front Pant Dart Angle (dart apex)										
	Front Pant Dart Length										
Back Pant Darts	Center Back Pant Dart Uptake										
	Side Seam Back Pant Dart Uptake										
	Back Pant Dart Position (dart legs)										
	Back Pant Dart Angle (dart apex)										
	Back Pant Dart Length	too long at apex	-1.5								
Darts	Number of Pant Front Darts										
	Number of Pant Back Darts	too many	-1								
Hems											
Fitting Area	**Item**	**Problem**	**Corrections Made**								
Pant Hem	Pant Hem Seam Level	too long	-1.5								
IV: Comfort											
Width Measurment Ease											
Fitting Area	**Item**	**Problem**	**Corrections Made**								
Total Waist Circumference	Pant Waist Ease										
Total Hip Circumference	Pant Hip Ease										

Questionnaire Design

To understand how subjects themselves assessed the fit of the 2D patterns developed from NX-12 3D to 2D system a questionnaire was developed and administered to the final 10 participants. It was also used to evaluate how they felt about using the 3D body scanner. The background and demographic information of the questionnaire was filled out using data that was collected from the consent form. See Appendix B.

Data Analysis

Research Objective 1

To create an evaluation tool that can be used to assess the fit and appearance of garments.

This research objective was addressed in the initial stages of the research. The rubric was created from the literature review collected on garment fit and appearance that strategically assessed major aspects of each garments fit and appearance. The rubric was separated into three parts which were used to evaluate the fit of a bodice, skirt, and pant patterns.

Research Objective 2

To determine the participants current fit issues with off-the-rack apparel products.

This research objective was met by analyzing the participants' answers to part one of the questionnaire administered after the participants were fit in their garments. Frequencies were used to determine 1) which garments the participants have problems with finding a “good” fit in, and 2) which areas of the body were the hardest for the participants to find a “good” fit. (See Appendix B.)

Research Objective 3

To determine the participants reaction and evaluation of the 3D body scanning process.

This research objective was met by analyzing parts three and four of the questionnaire distributed to the participants after the fitting session. The data collected from parts three and four of the questionnaire were put into frequency charts to determine 1) the participants comfort with using the 3D body scanner, 2) how they feel about 3D body scanner verses traditional shopping experience, and 3) their interest in using the 3D body scanner in a traditional shopping environment. (See Appendix B.)

Research Objective 4

To identify the process that will enable 3D to 2D patterns to be used for garment design.

This research objective was met using a descriptive analysis of the situations encountered when creating 3D to 2D patterns from the scanned individuals’ digital 3D point cloud image. The descriptive analysis was categorized into problems that occurred in the 3D to 2D extraction process and problems that occur in the Gerber AccuMark PDS system import process.

Research Objective 5

To determine how all participants’ 3D to 2D patterns should be changed to be in accordance with the garment evaluation tool.

To meet the objective, the data collected in the fitting sessions and entered into the garment assessment tool was used. For all participants' data the following analysis was conducted. For the first part of the analysis a discussion of all the changes that were done to each garment was explained. Furthermore, the frequency of each fit and appearance issue was determined for each garment. The frequencies of the changes were created to determine which problems were common and which were more likely to occur on an individual basis.

Research Objective 6

To determine how groups of participants' 3D to 2D patterns should be changed to be in accordance with the evaluation tool.

In order to meet the objective, data collected in the fitting sessions was used. For the analysis the participants were separated into groups by BMI, height, weight, bust measurement, waist measurement, and hip measurement. The categories were determined as follows:

- The Body Mass Index (BMI) of the participants was determined using the Body Mass Index Table (HHS & USDA, 2005). (See appendix D.) This table is a method of determining the degree of excess weight that is on the body based off of the weight and height of the individual. (Bariatricedge, n.d.)
- Heights and weight classifications of the participants were determined using the National Center for Health Statistics and National Center for Chronic Disease Prevention and Health Promotion May (2000) study that

determined the 20 year old height percentiles for women. (See tables 4 and 5, and appendix D).

Table 4. Height classifications of participants.

HEIGHT			
75% Percentile	> 66"	> 5' 5"	**Tall Stature**
50% Percentile	62.5" – 66"	5' 2.1" – 5'5"	**Average Stature**
25% Percentile	< 62.5"	< 5' 2.1"	**Short Stature**

Table 5. Weight classifications of participants.

WEIGHT		
75% Percentile	> 145	**Large**
50% Percentile	115 - 145	**Average**
25% Percentile	< 115	**Small**

- The circumferential measurement categories were determined using the ASTM-5585 Missy Sizing standard size measurements. The categories chosen to include x-small (size 2 and smaller), small (sizes 2-6), medium (sizes 8-12), large (sizes 14-18), and extra large (sizes 20+) and were based off of the sizing systems bust, waist, and hip measurements (see appendix D).

Each of these groups was used to determine if the number of changes to the garments were influenced by the participants BMI, height, weight, or circumferential measures. To do this first the frequency and percent of each change overall, by fit, and by appearance were determined for each garment. Then, the frequency and percent of each issue by group was tested for relationships to overall changes, fit changes, and appearance changes using a one way analysis of variance (ANOVA) test.

Research Objective 7

To determine how participants rate the fit of the garment made from the 3D to 2D verses off-the-rack garments available in the marketplace.

The above research objective was addressed using part two and three of the questionnaire distributed to the participants after the fit session. The information from these sections of the questionnaire was expressed in frequency charts that showed 1) how strongly the participants felt about the fit of each garment verses off-the-rack fit options, and 2) how the fit of the product would translate into future decision on using 3D body scanners. (See Appendix B.)

Chapter 4: FINDINGS

Garment Evaluation Tool

The first objective of the research was to develop a garment evaluation tool that would assess the bodice, skirt, and pant garments fit and appearance. In researching fit and appearance there was no literature found that included a garment evaluation tool for use in determining the fit and appearance of the garment and the methods to correct the garment. Therefore a tool was created through an exhaustive literature review conducted on important areas of fit and garment design principles discussed in chapter two.

The major areas of the body that were determined to contribute most to the fit of the garment were the shoulder length, bust circumference, waist circumference, hip circumference, back waist length, sleeve length, crotch depth, crotch length, and armhole fit. Ultimately, these areas of the body were considered 'fitting areas' of the body on the garment evaluation tool. Secondly, the key areas of the body were evaluated further to determine what the characteristics of a "good" fitting garment were with respect to each specific area. The characteristics of "good" fit were found to be determined by four major principles. These four key principles are the design of the garment, fabric used in the garment, appearance of the garment such as darts and seams, and lastly the comfort derived from the garment. Ultimately, this information lead to the development of the 'items' area of the garment evaluation tool which determined that the variables (Editors of Creative Publishing International, 1987; Handford, 2003; Joseph-Armstrong, 2006; Shepherd, 1997) to impacted fit were:

- Seam length

- Seam uptake
- Seam level
- Dart uptake
- Number of darts
- Gaping
- Crotch rise

The variables taken from the literature (Editors of Creative Publishing International, 1987; Handford, 2003; Joseph-Armstrong, 2006; Shepherd, 1997) that impacted the garments appearance were:

- Seam position
- Seam angle
- Dart length
- Dart leg position
- Dart apex position

All of these elements are directly related and dictated by the style and ultimate end use of the garment created. A written description of how the garment appearance and fit variables should look as they relate to the body was explained in the 'ideal fit' area of the garment evaluation tool. Lastly, the column of the tool labeled 'problems' was used to track the issues with the garments fit and appearance as well as the changes needed to correct these problems. See appendix C for the fit and appearance evaluation tool developed for this study.

Participant Information

In this exploratory study, 10 females between the ages of 21 to 26 were scanned and fit with a bodice, skirt, and/or pant developed from [TC]^2's 3D to 2D pattern unwrapping software. The average age of the participants was 23 years old. The majority of the participants, 6, were Caucasian while the remainder of the participants, 4, were African American. The height of the participants ranged from 62 inches or 5 foot 2 inches to 72 inches or 6 foot tall with the average height being 66.2 inches or 5 foot 6.2 inches tall. This allowed for a 10 inch difference between the shortest and the tallest participant creating enough variety in participants to assess the program as it relates to height. The average weight of the participants was 136.8 pounds with the highest weight of the group being 176 pounds and lowest weight being 118 pounds. The difference in weight also varied from the smallest to the largest participant. For weight overall there was a difference of 58 pounds. The majority of the participants, 5, were classified by the Body Mass Index as being of a healthy weight compared to their stature. However, 2 of the participants were classified as being obese and 3 were classified as being underweight. There were no participants in the study that were classified as being overweight. The bust measurements of the participants ranged from 30.84 inches to 43.18 inches which was a difference of 12.34 inches, the waist measurement ranged from 24.89 inches to 34.48 inches which was a difference of 9.59 inches, and the hip measurement ranged from 36.69 inches to 46.07 inches which was a difference of 9.38 inches. Ultimately, these measurements placed the participants in different size classifications as they relate to the USDA body mass index table, ASTM 5585 sizing standards, and the National Center for Health Statistics height and weight percentiles (see Appendix D).

Participant Fit Issues

The second objective was to determine the participants' current fit issues with off-the-rack garments. This objective was answered using frequency charts of the participants' answers to part one of the questionnaire administered after the fit session was completed. The majority of the participants, 77.8%, responded that finding off-the-rack clothing with "good" fit was an issue. The remaining 22.2% had no problems finding off-the-rack apparel products that fit "good" in the marketplace.

The highest percent of participants, 77.8%, have problems finding off-the-rack pants that provide a "good" fit. Along with pants overall being difficult for the participants to find a "good" fit, the majority of participants, 66.7%, have problems with finding pants with suitable hem lengths a well.

Shirts were considered by 44.4% of the participants to be difficult to find a "good" fit. Furthermore, shirts with satisfying sleeve length were also considered difficult to find for 33.3% of the participants. Jackets were considered difficult to find a "good" fit by 33.3% of the participants. However, "good" fitting off-the-rack skirts were not considered by any of the participants in this sample to be difficult to find.

The bust and waist was considered to be difficult to find a "good" fit by only 44.4% of the participants. Hips and thighs were also rated difficult to fit by 22.2% of the participants. However, none of the participants had issues finding garments that fit their biceps or neck properly.

Participant Assessment of 3D Body Scanning Process

The third objective was to determine the participants' reaction and evaluation of the 3D scanning process. This objective was met using frequency charts and average percents of the participants' answers to parts three and four of the questionnaire administered after the fit session was completed.

Comfort with using body scanner. The majority of the participants, 88.9%, in the study at minimum agreed that using the 3D body scanner was as comfortable as using a traditional dressing room with an average rating of 6 (agree) on a scale of 1. “I strongly disagree” to 7. “I strongly agree”. Overall, 55.6% of the participants strongly agreed with this statement while only 11.1% slightly disagreed with this statement (see figure 36).

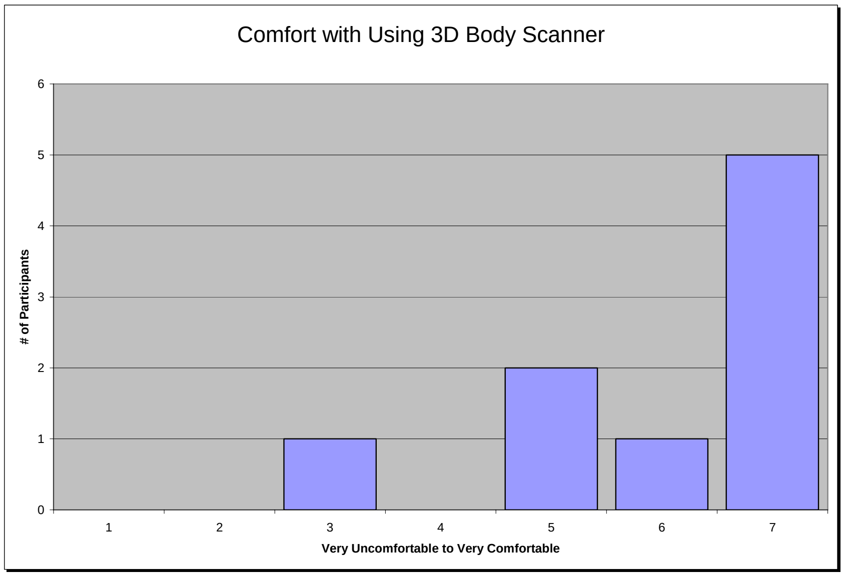

Figure 36. Comfort with using 3D body scanner.

Excitement with using body scanner. The majority of participants, 77.7%, slightly agreed to strongly agree that using the 3D body scanner was more exciting than the traditional off-the-rack retail experience. In all, 44.4% of the participants strongly agreed with this statement and only 11.1% disagreed with this statement. The average rating for this question was 5.66 (see figure 37).

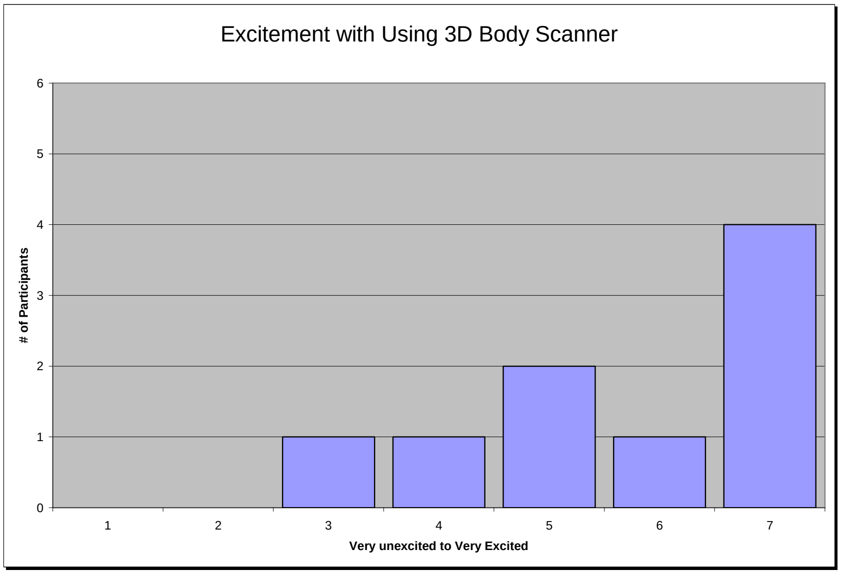

Figure 37. Excitement with using 3D body scanner.

Reuse of body scanner. Participants on average slightly agreed that they would use the 3D body scanner again. With closer inspection of the responses it was found that the majority of participants, 66.6%, slightly too strongly agreed that they would reuse the body scanner while 22.2% were unsure. The average rating for this question was 5.22 (see figure 38).

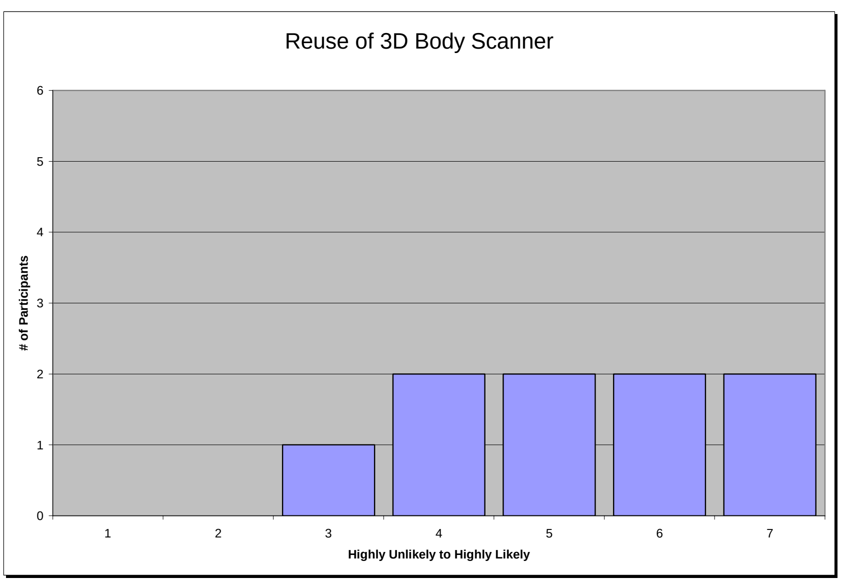

Figure 38. Reuse of 3D body scanner.

Anticipated retail use of body scanner. Fifty-five point five percent of the participants were slightly interested with using the 3D body scanner in a retail setting, while 33.3% were not interested. On average, the participants were in-between neutrally interested and slightly interested in using the scanner in a retail setting with a rating of 4.55 (see figure 39).

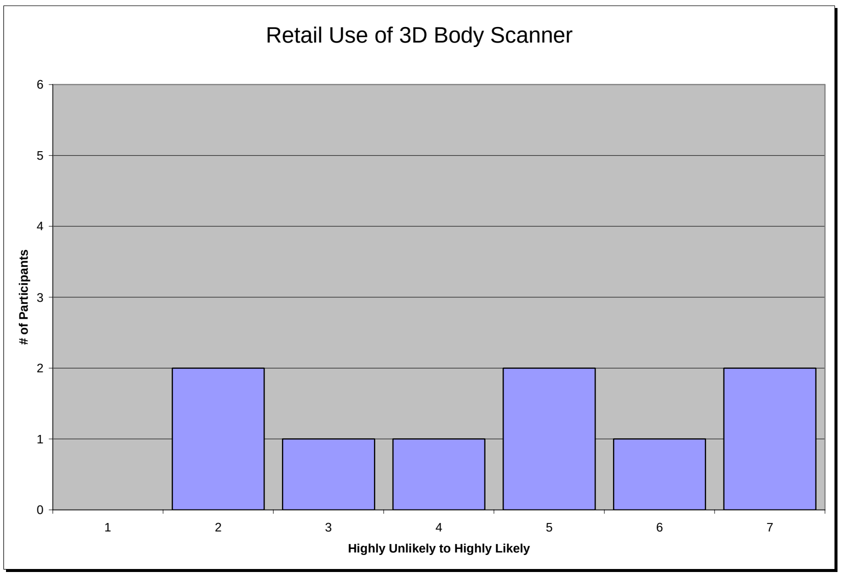

Figure 39. Anticipated retail use of 3D body scanner.

Recommendation intentions for body scanner. The majority of participants, 77.7% felt like they would recommend the body scanner to other people who have difficulty finding garments that fit. Thirty-three point three percent of participants strongly felt that they would recommend the scanner while only 22.2% did not feel that they would. The average rating for this question was 5.88 (see figure 40).

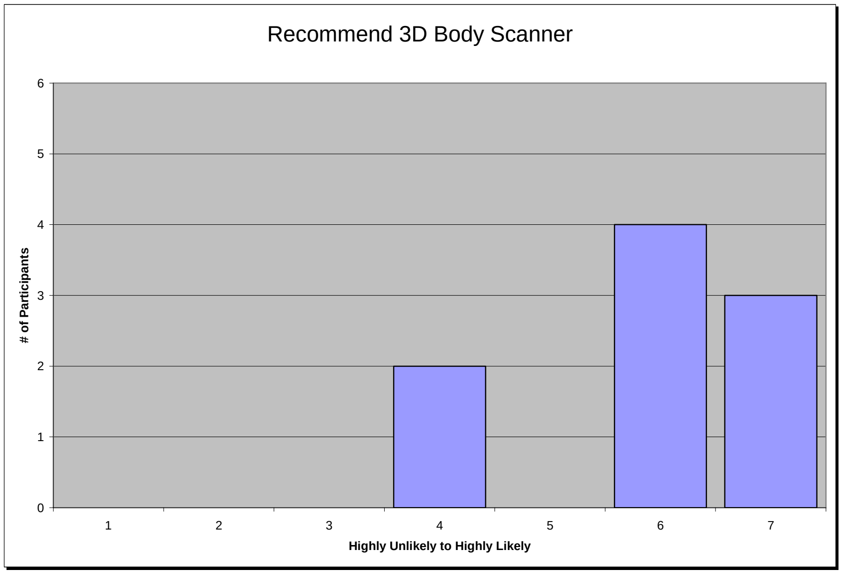

Figure 40. Recommendation intentions for 3D body scanner.

Interest in finding retailers with body scanners. Sixty-six point six percent of participants were interested in finding companies that use body scanning to create their apparel products. On average, participants were only slightly interested (rating of 5.11) in finding companies that use scanning technology in their product development process (see figure 41).

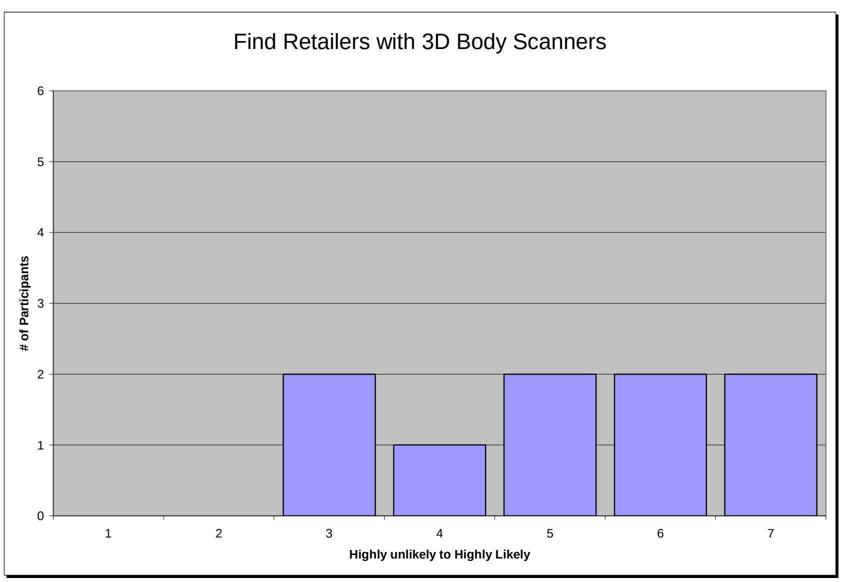

Figure 41. Interest in finding retailers that use body scanning.

Concerns with body scanner. On average the participants did not have concerns with privacy or confidentiality in using the 3D body scanner. On a scale of 1. "Strongly unconcerned" and 7. "strongly concerned", 33.3% percent had slight concerns with privacy, and 11.1% had slight concerns with confidentiality for the image and measurements that were extracted from the scanning system. The majority of the participants, 33.3% did not have concerns at all with confidentiality with using the scanner (see figures 42 and 43).

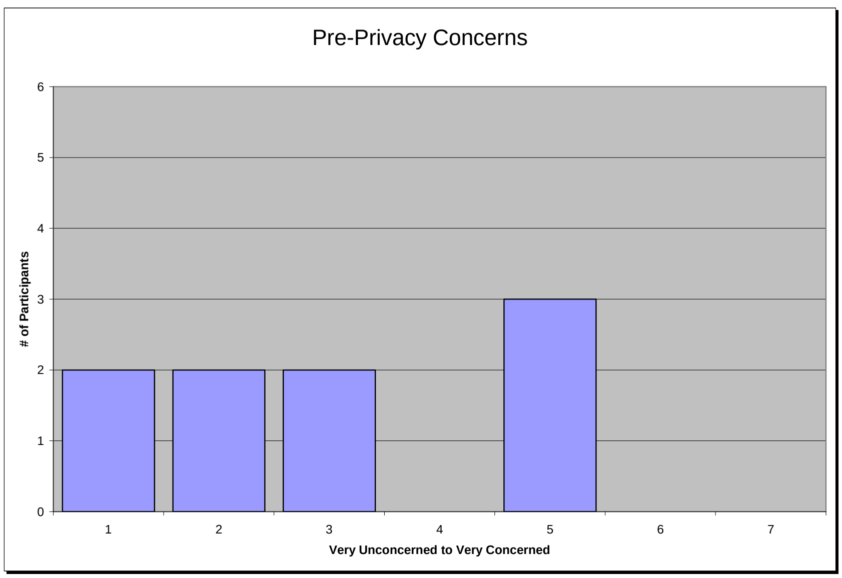

Figure 42. Privacy concerns with using 3D body scanner.

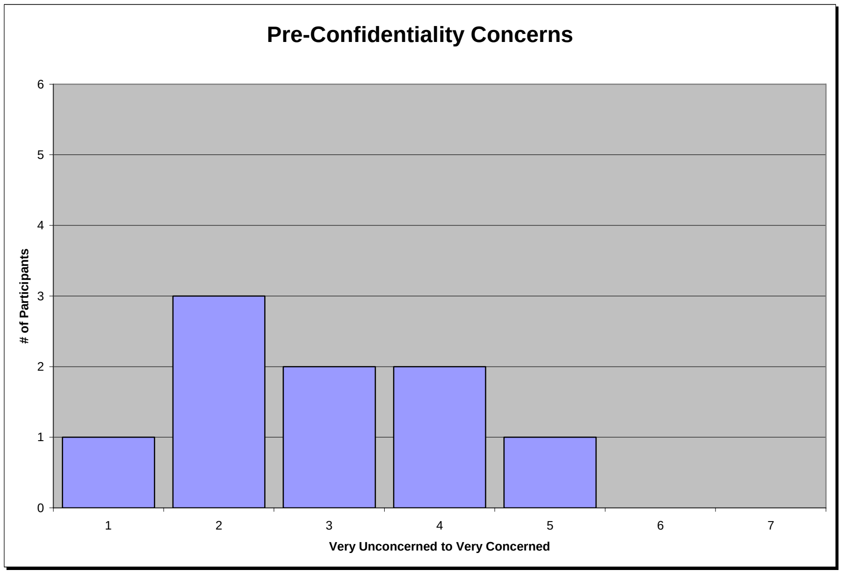

Figure 43. Confidentiality concerns with using 3D body scanner.

The majority of participants, 62.5%, were at least slightly concerned with the sanitation of the 3D body scanner. The remainder of the participants, 37.5%, was not concerned with the sanitation of the 3D body scanner. However, health issues developing from the use of the 3D scanner were not a concern for the majority of the participants. This is evident by 77.7% of the participants responding that they were not even slightly concerned about their health during the scanning process (see figures 44 and 45).

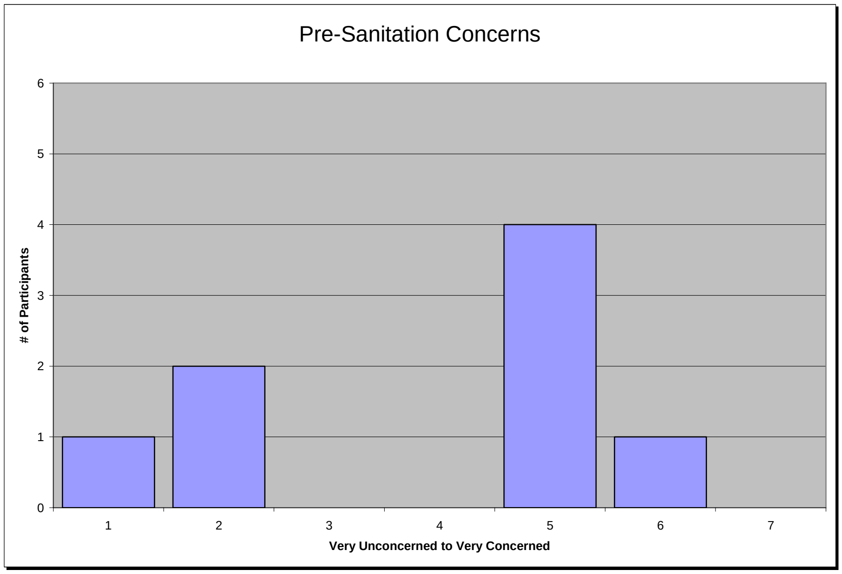

Figure 44. Sanitation concerns with using 3D body scanner.

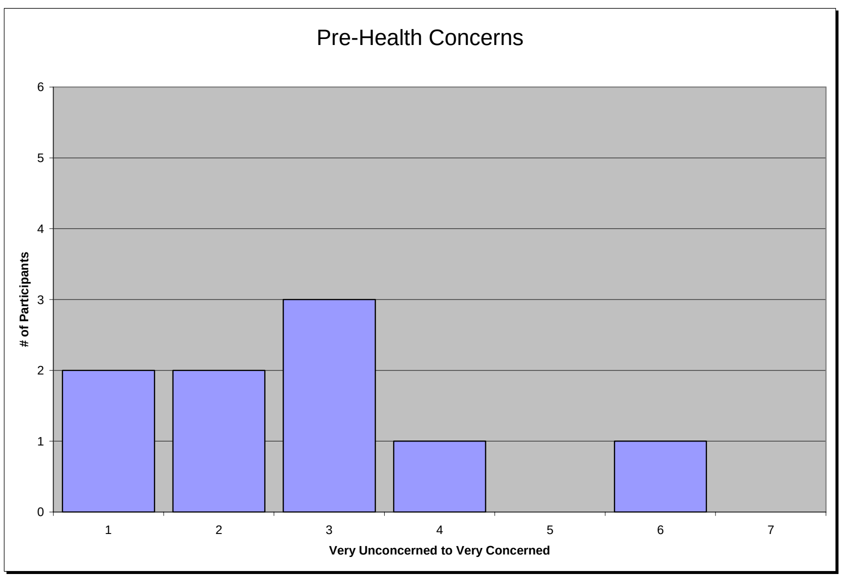

Figure 45. Health concerns of using 3D body scanner.

Participants were on average slightly unconcerned to neutral about the appearance of the scanning image. The uneasiness about the image ranged from highly unconcerned to concerned (see figure 46).

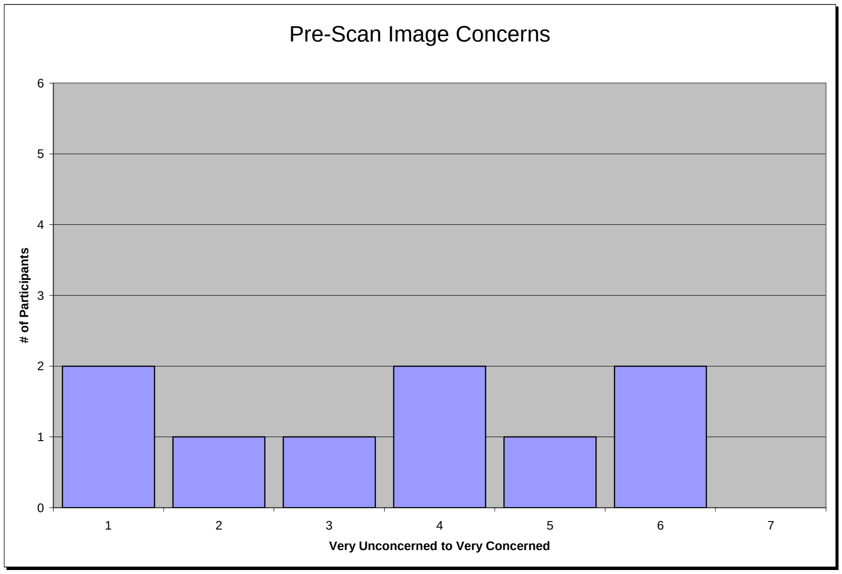

Figure 46. Scan image concerns of using 3D body scanner.

The participants were asked if there were any changes in how they rated the issues of sanitation, health, confidentiality, privacy, and apprehension about the scan images appearance after the first use of the 3D body scanner. Twenty-two point two percent of the participant's prior concerns with using the scanner either increased or decreased for particular aspects. Concerns with the privacy, health, and appearance of the scanned image decreased for 11.1% of all participants. Furthermore, 22.2% of the participants' confidentiality and sanitation concerns decreased after using the 3D scanning system. However, for 11.1% of the participants, the apprehension with the appearance of the scanned image increased after using the scanner. (See appendix B).

Analysis of 3D to 2D Pattern Development Process

The fourth objective was to identify the step in the process that would enable 3D to 2D patterns to be used in garment design. This objective was answered by descriptively explaining the process and issues that occurred during the development of the 3D to 2D pattern. The process of creating the garments on the 3D point cloud image in the NX-12 system as well as the characteristics of the 2D pattern imported into Gerber AccuMark PDS had various problems. These problems will be explained in the following sections on 3D garment extraction problems and 2D pattern extraction problems.

3D Garment Extraction Problems

Bodice extraction problems. There were a number of garment extraction problems that occurred during the NX-12 3D to 2D pattern unwrapping process. For the bodices, 8 out of 10 of the patterns were successfully extracted without any issues using the system. One of the issues that occurred during the extraction of the bodice was that the system incorrectly placed points off of the center plumb line of the body which ultimately resulted in an incorrect and unusable imported pattern (see figures 47-50).

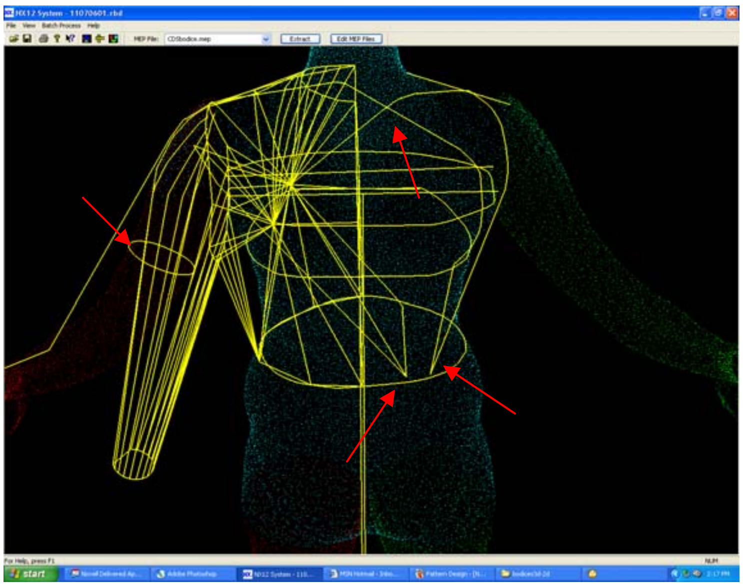

Figure 47. Image of incorrect 3D bodice extraction.

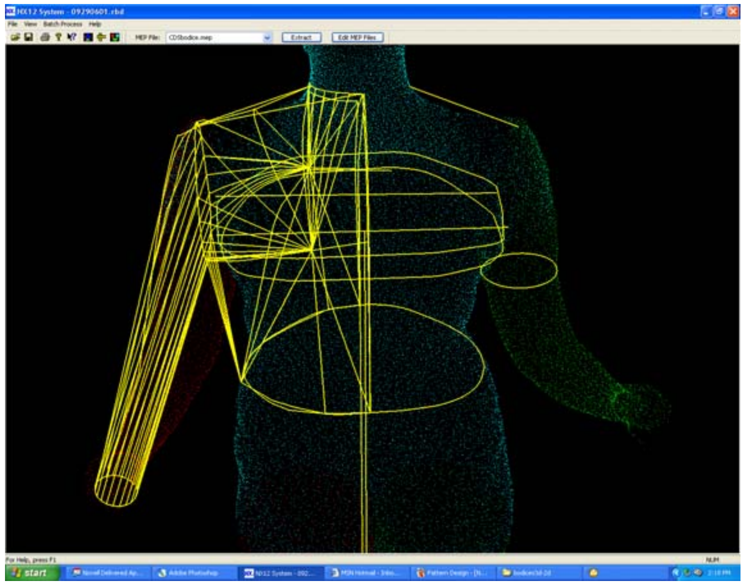

Figure 48. Image of correct 3D bodice extraction.

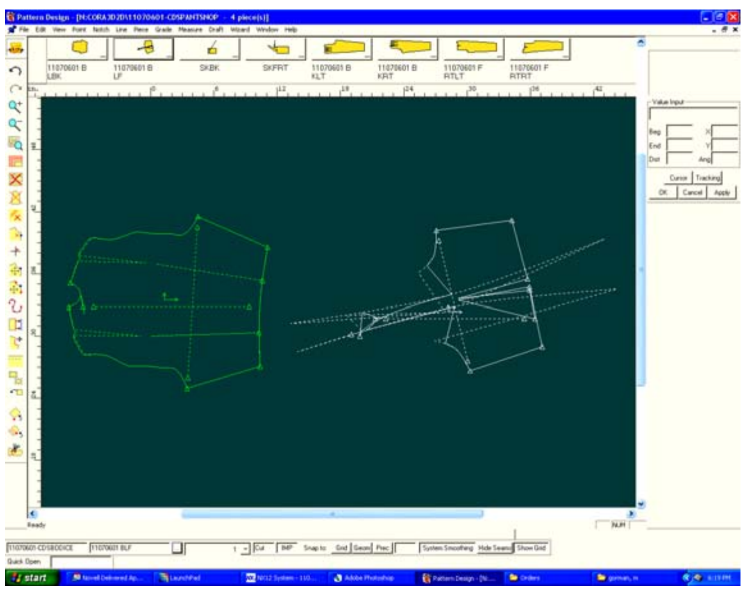

Figure 49. Results of incorrect bodice extraction.

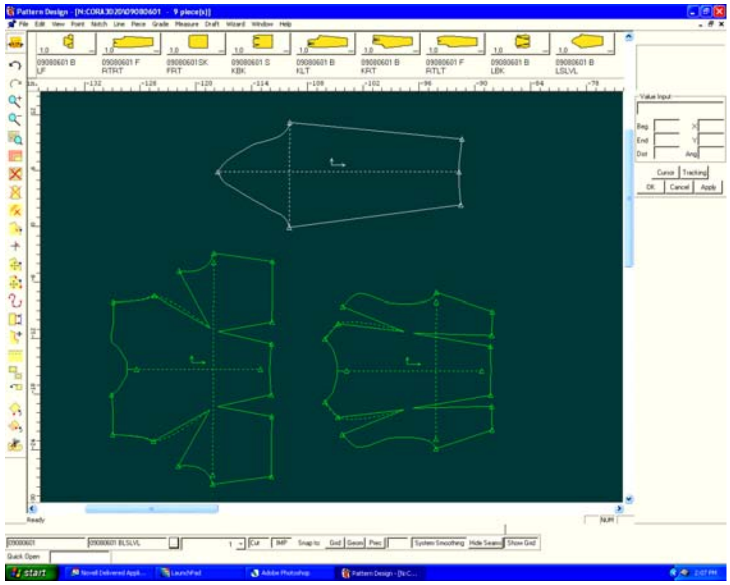

Figure 50. Results of correct bodice extraction.

Skirt extraction problems. The skirts extraction in NX-12 3D to 2D software program exhibited more noticeable problems than the bodice. Ultimately, 7 out of the 10 of the extractions were completed successfully. For the three skirts that were extracted incorrectly, the problem was stray points that altered the skirts 3D image and 2D imported pattern ultimately making the patterns unusable (see figures 51-54).

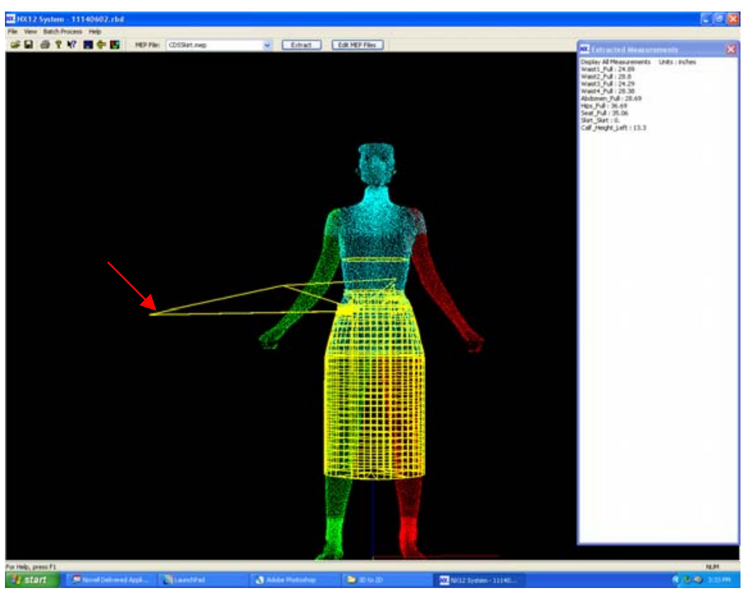

Figure 51. Image of incorrect 3D skirt extraction.

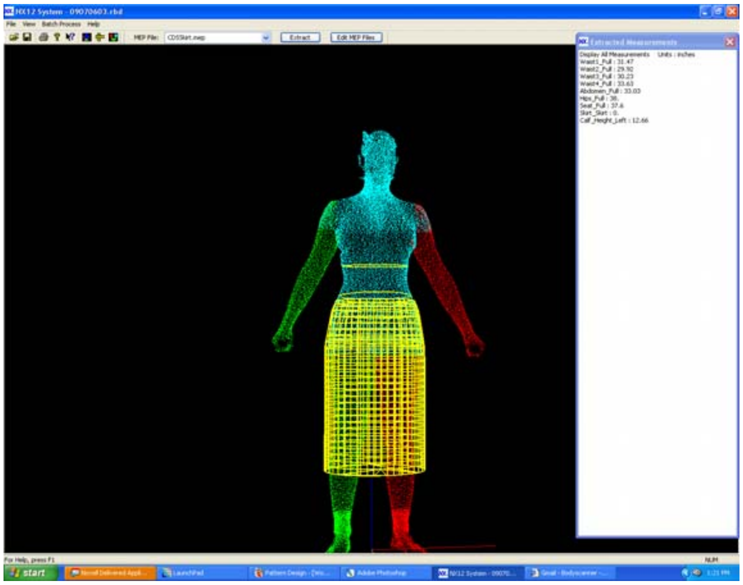

Figure 52. Image of correct 3D skirt extraction.

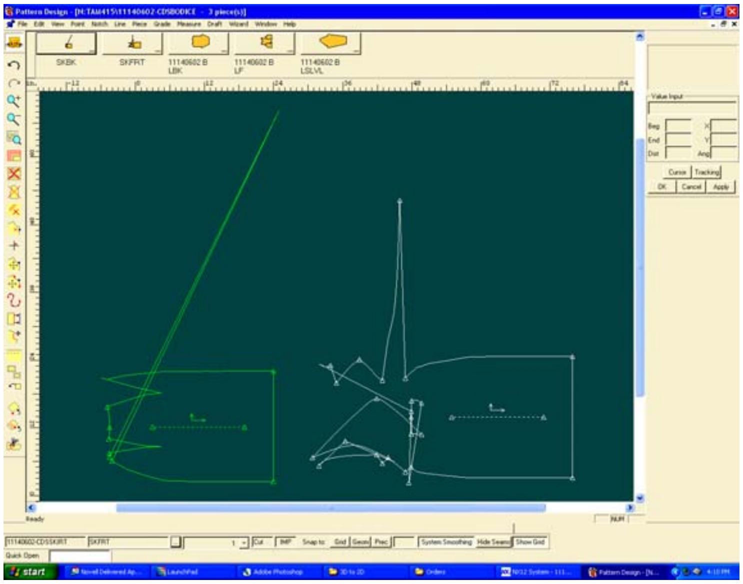

Figure 53. Results of incorrect skirt extraction.

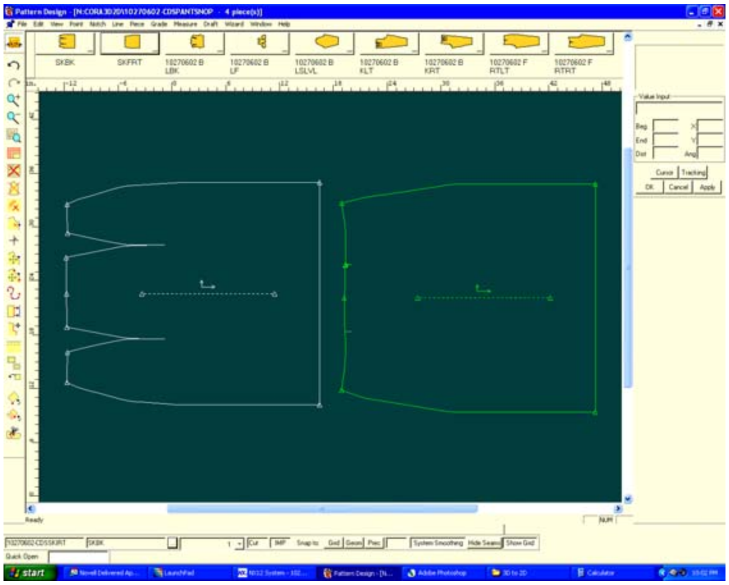

Figure 54. Results of correct skirt extraction.

Pant extraction problems. For the pant extraction, 7 out of the 10 participants' patterns extracted correctly. For 2 of the participants their 3D extraction had similar difficulties that were present in the unusable skirt extraction images, in that there were stray points that altered the ultimate import of the 2D pattern rendering it unusable (see figures 55-58). The problems with the pant pattern were more obvious mainly because the program creates a 2D pattern of the pant as well as shows the 3D image of the pant on the 3D point cloud in the NX-12 system. This feature is not available for any of the other garments. Another issue not existing in the bodice and skirt extraction was the unresponsiveness of the program during the extraction of one participant's pant. This situation happened only for this one participant every time the pant was extracted. However, it did not happen to this participant during the extractions of other garments such as the bodice and skirt.

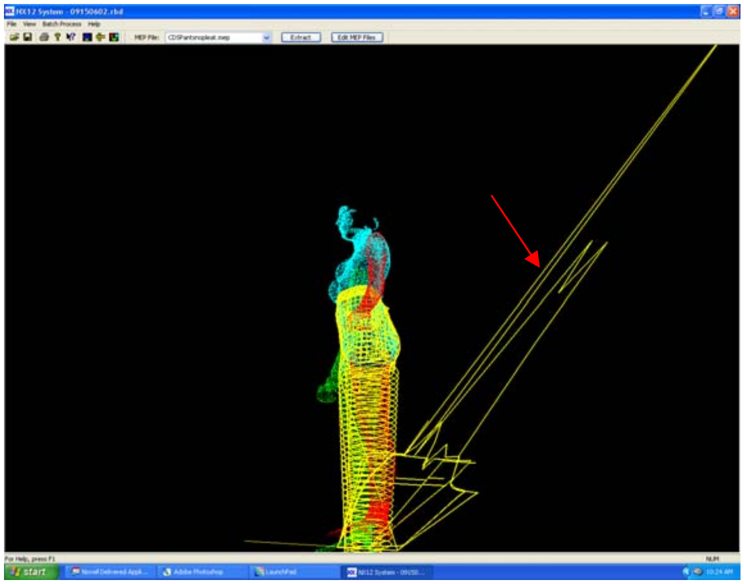

Figure 55. Image of incorrect 3D pant extraction.

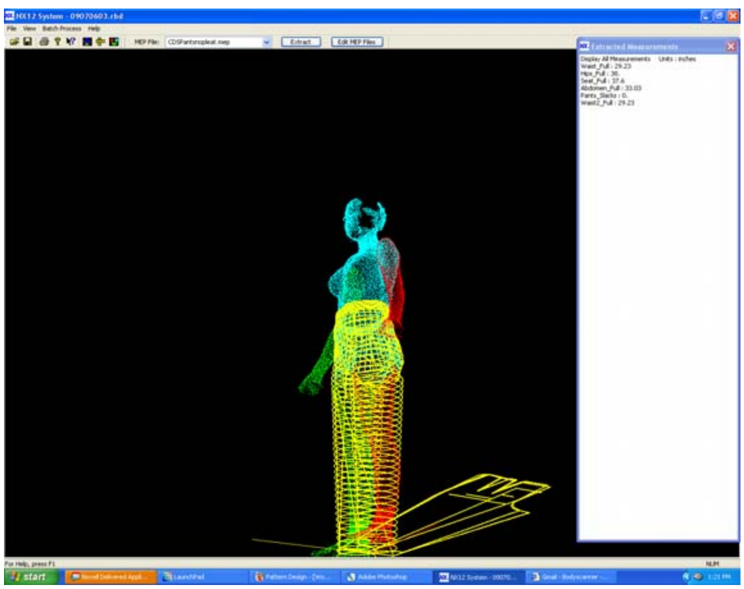

Figure 56. Image of correct 3D pant extraction.

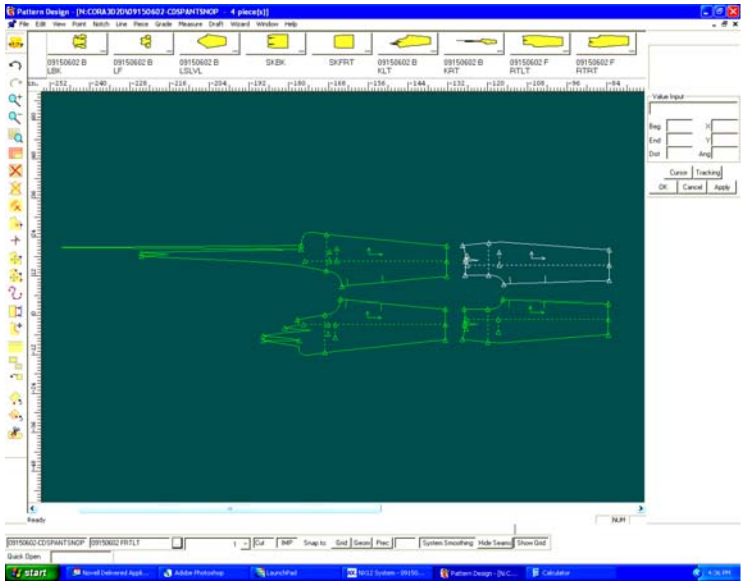

Figure 57. Results of incorrect pant extraction.

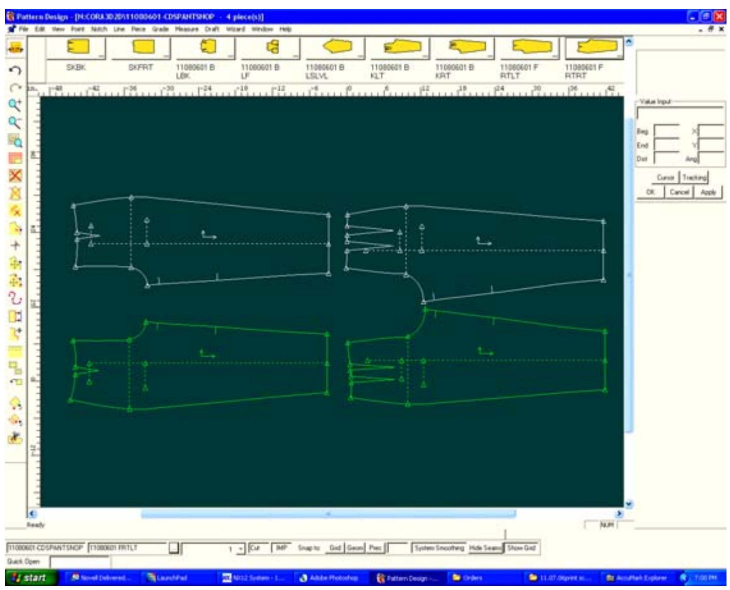

Figure 58. Results of correct pant extraction.

Other 3D extraction problems. Other problems did occur during the unwrapping process that was not evident until imported into Gerber AccuMark. Of the 9 out of the 10 bodices that at first glance appeared to be extracted properly, 1 was completely missing a sleeve pattern once imported into Gerber. For the purposes of this study, the bodice without a sleeve was still usable because the sleeve was not needed to test for fit of the bodice. For the pant pattern one noticeable problem discovered after import was that all but one of the usable 2D pant patterns had imported with a curved waist point at the side seam position. This problem was easily corrected and therefore the garments were still used for fit analysis (see figure 59). Other more universal problems occurred with the patterns that will be further explained in the section below on 2D pattern extraction problems.

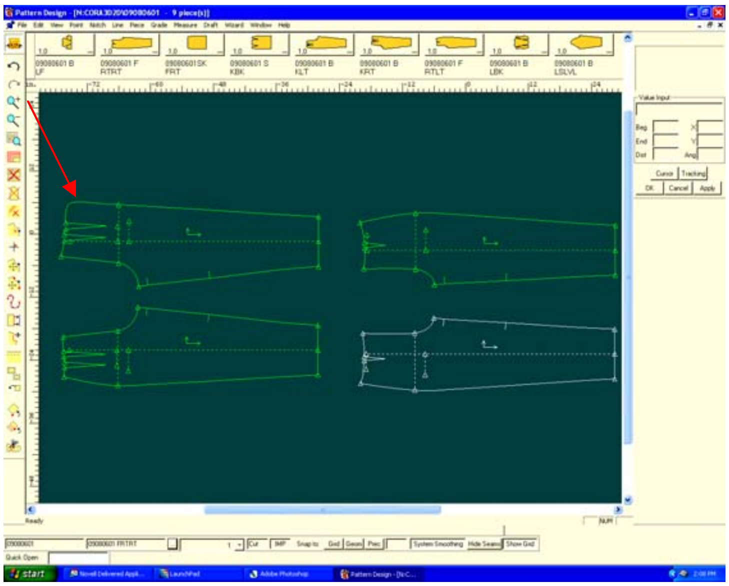

Figure 59. 2D pant extraction with rounded waist defect.

2D Pattern Extraction Problems

In many cases the NX-12 system created a garment without any or with very little problems. These were the garments that were ultimately used in the fit analysis study.

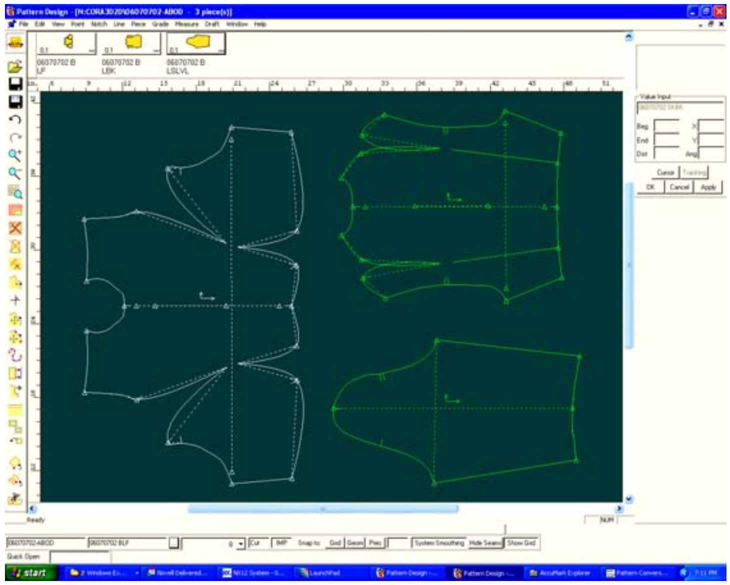

Figure 60. Example of typical imported bodice pattern into Gerber.

However, all of the garments that were imported into Gerber and used in the final fit study had key problems that were evident once translated into Gerber AccuMark PDS system. Each of these issues needed to be addressed before creating the marker and sending the pattern to the Gerber cutter to be cut. Below is a list of the issues that were encountered.

*Additional lines***.** Each piece first had to have all unnecessary lines removed. These extra lines were seam allowance lines that were automatically added to the pattern by the NX-12 system and caused problems with the cutter correctly understanding what it should consider the outside cutting edge of the pattern piece. The pant pattern was the only pattern that did not have these additional lines associated with it. This is because within the parameters of creating the pant 3D to 2D extraction profile the option of turning off seam allowances was present. However, for the bodice and skirt block seam allowance lines were present and therefore had to be removed (see figure 61).

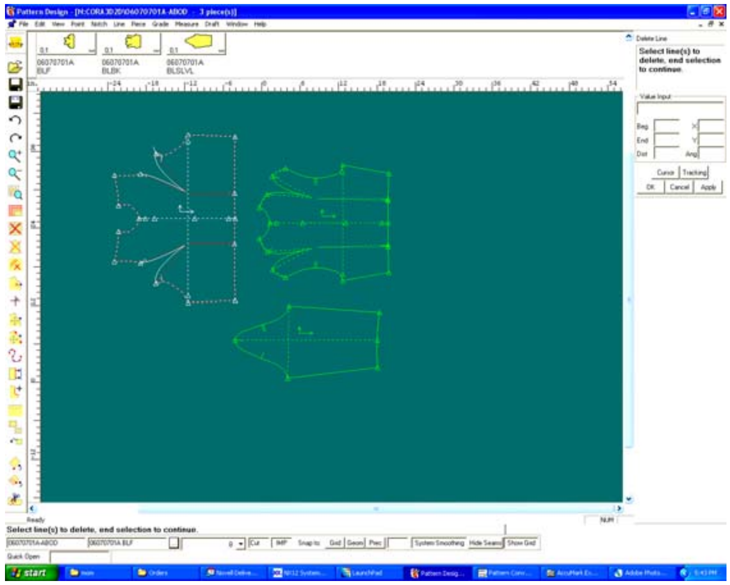

Figure 61. Example of 2D patterns additional lines.

Notches. In all patterns extra notches had to be deleted. This was because the patterns imported in from the NX-12 system with additional, unnecessary notches (see figure 62).

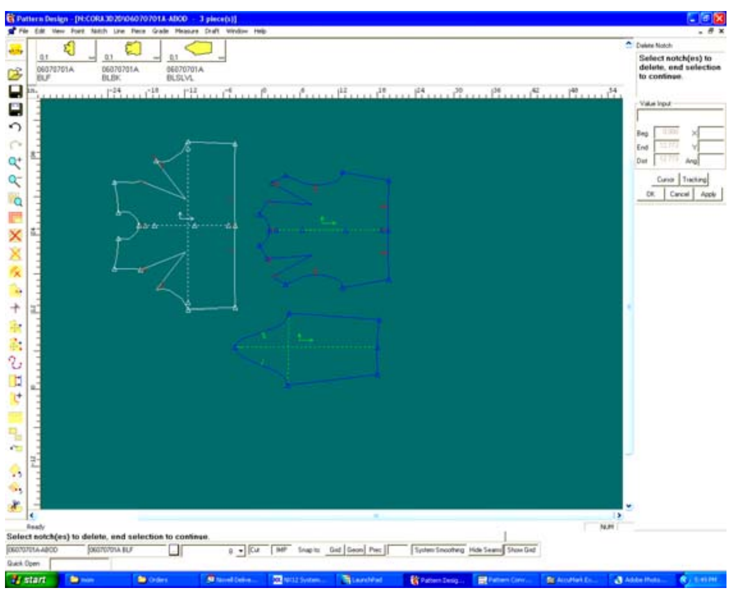

Figure 62. Example of 2D pattern notch removal.

The notches also imported in from the NX-12 system classified as notch category “#1” or “#6”. These two categories were not compatible with the Gerber cutter installed at North Carolina State University, and therefore needed to be changed to a notch “#2” for proper cutting of the pattern piece. This was done by using the “attribute” function in Gerber and changing the notch category to notch “#2” (see figure 63).

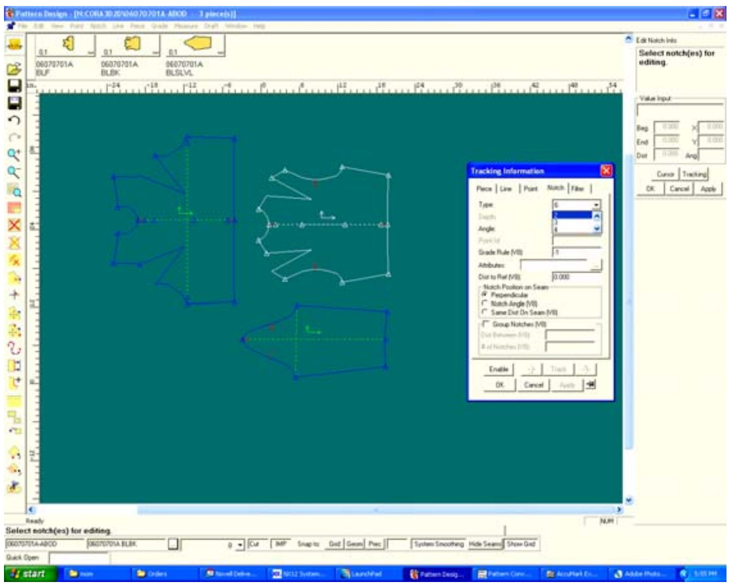

Figure 63. Example of 2D pattern notch attribute changes.

Rounded lines. In some cases the imported pattern had rounded lines when they should have been straight. This was especially evident in darts that were created in the skirt pattern pieces and shoulder and dart lines created in the bodice pattern pieces (see figure 64). There are two procedures that had to be employed to correct this problem:

1. One way this problem was fixed was by changing the attributes of the points in the point attribute function. This was done by highlighting the points on the line of question and changing the attribute from an “S” (curved) to “N” (straight). (See figure 65).

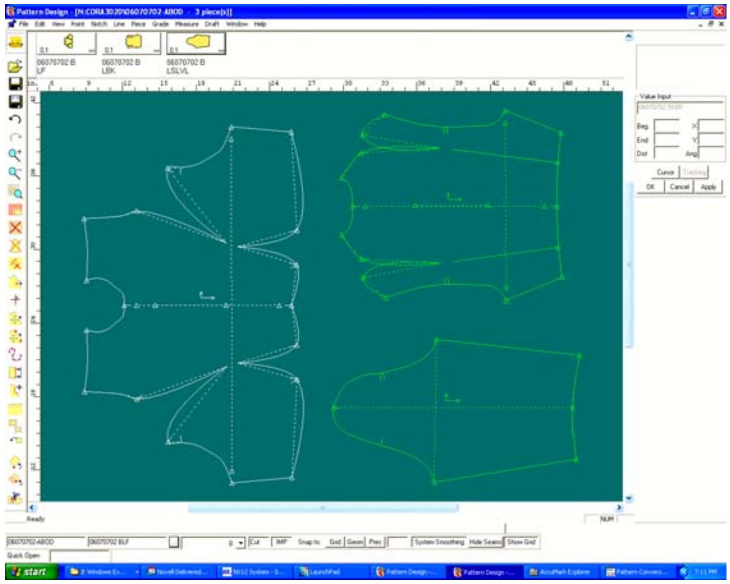

Figure 64. Example of 2D patterns rounded lines.

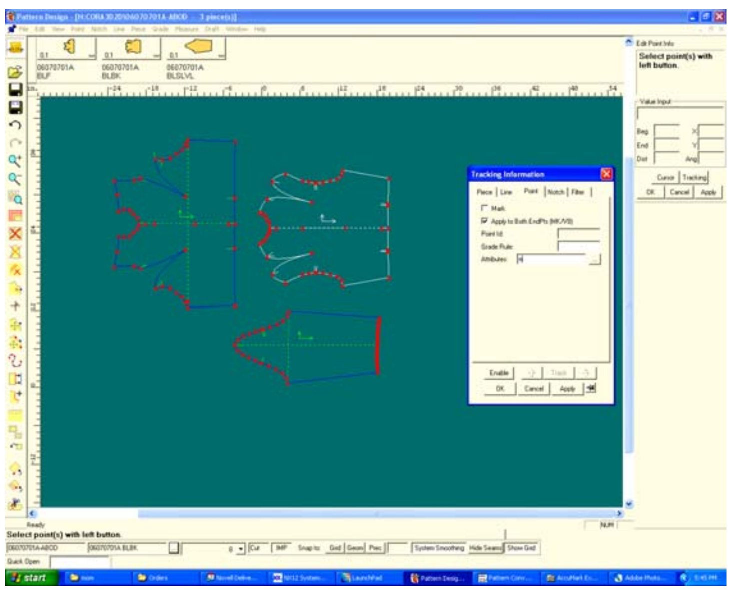

Figure 65. Example of 2D pattern point attribute changes.

2. Another way that this problem was fixed was by deleting points that created the curved shaped line. This was necessary when there were extra points in the line that was creating and holding the shape regardless of the attribute of the points. In the delete point function the points creating the curve were highlighted and deleted.

Connected and disconnected lines. In some cases the garments lines were connected to one another and/or disconnected from one another in locations where they should either have been split or merged. This was especially important to note on the side seams of the garment, as well as around the darts, mainly because the line connectivity can interfere with closing of the darts and/or adding of seam allowances. To correct this problem, the functions of "split line" and "merge line", found under the line menu, were used.

Darts. Another problem that was found in this research was that the darts in the garment did not import into the CAD system as recognized darts. In many cases the intended dart could be converted to a dart by using the "convert to dart" function under the pieces/darts menu (see figure 66).

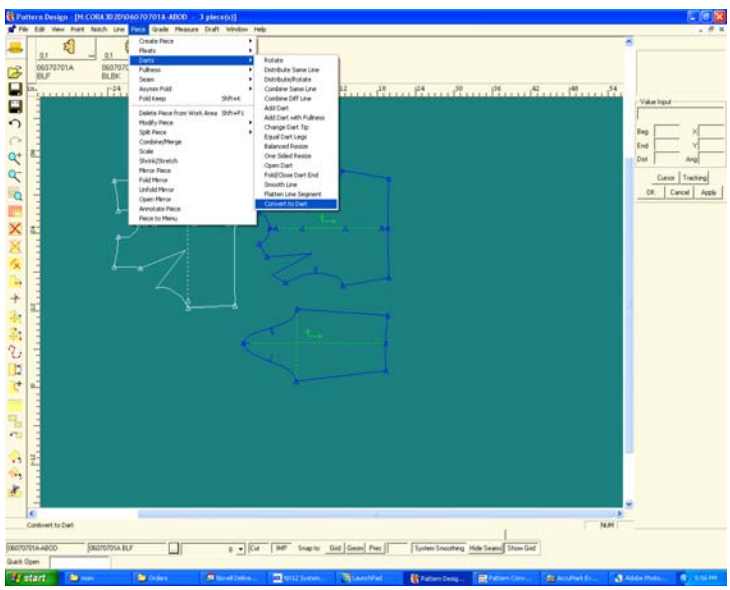

Figure 66. Example of 2D pattern dart recognition process.

When convert to dart did not work, there was likely to be one or all of four problems:

1. There was a point located on one of the dart legs that needed to be erased

2. The dart legs were not joined at the dart apex
3. The dart legs were not split from the adjacent line
4. There was a point on the adjacent line that was close to the dart that could be confusing the system into thinking there was not a dart

Another problem that was associated with the dart legs was that some of the imported darts were not even. This problem was corrected by using the function “equalize dart legs” under the drop down menu “piece” to “dart”.

Analysis of 3D to 2D Garments

The fifth objective was determining how all participants’ 3D to 2D patterns should be changed to be in accordance with the evaluation tool developed in research objective one. This objective was met using frequency charts and average percents of the garment changes that were needed. Information was segmented into categories which assessed bodice, skirt, and pant fit and appearance issues (see appendix E). After the bodice fit and appearance issues were determined they were then analyzed by number of participants with these issues. To determine this each garment was assessed first by determining the overall changes needed for each participant’s garment and then further separated by fit and appearance changes needed. This segmented analysis was later used for further analysis of data in research objective 6.

Bodice Fit and Appearance Analysis

Bodice Fit and Appearance Issues

Bodice shoulder seams. There were a number of fit and appearance issues concerning the shoulder seams of the bodice. The bodice shoulder seam position was found to be slanted to the front of the body at the neck point for 38% of the participants and slanted to the back of the body at the armhole for 25% of the participants (see figure 67). To fix the forward slanting of the shoulder seam at the neck point, an average of 0.88 inches was added to the front and removed from the back of the pattern at the shoulder seam neck point. On average, 0.63 inches was removed from the shoulder seam at the front armhole point and added to the back armhole point to fix the slanting back of the shoulder seam at the armhole. (See appendix E).

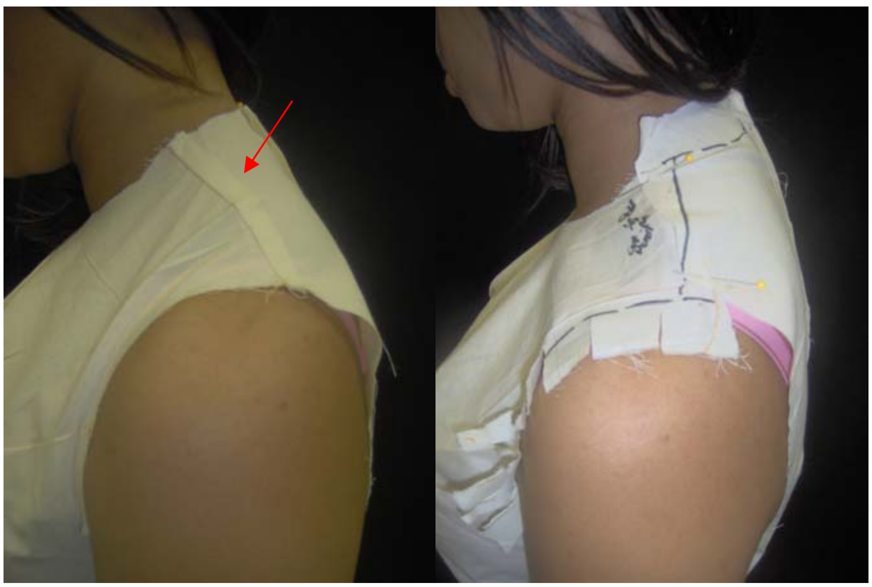

Figure 67. Shoulder seam slant fit issue before and after changes.

The lengths of the shoulder seams were also inaccurate for a number of the participants. Thirty-eight percent of the participants' shoulder seams at the back armhole were too short and 25% of participants' front armholes were too short at the shoulder seam. The back and front armhole was too long at the shoulder seam for 13% and 25% of the participants respectively. When assessing the shoulder seam length at the neck, 88%, of participants' front length at the shoulder seam was too long and all of the participants back neck lengths were too long. (See appendix E)

Bodice neckline. Similar to the shoulder seam, the center front and center back neckline was too high for the majority of participants (see figures 68, 71, and 74). The center front neckline was too high for 75% of the participants and needed to be dropped an average of 0.92 inches. The neckline in the back was too high for 88% of participants and had to be dropped an average of 0.79 inches. Only one participant had gaping present at the shoulder seam neckline point which had to be taken in by 0.25 inches. (See appendix E)

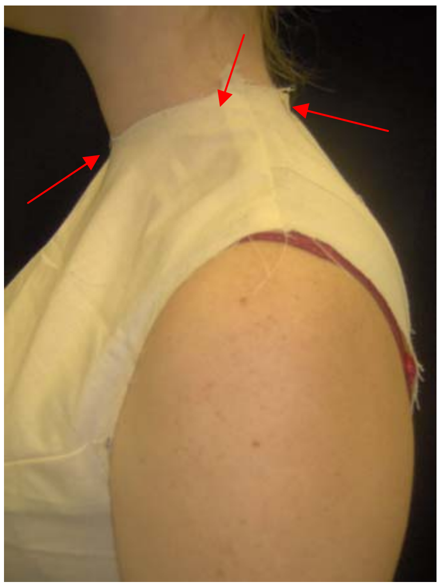

Figure 68. Shoulder seam neck point and center front and back neck too high.

Bodice side seams. The location of the side seam was too far from the center front (see figure 69) of the body for more than half, 63%, of the participants. The side seam had to be moved toward the front of the body an average amount of 1.55 inches. (See appendix E).

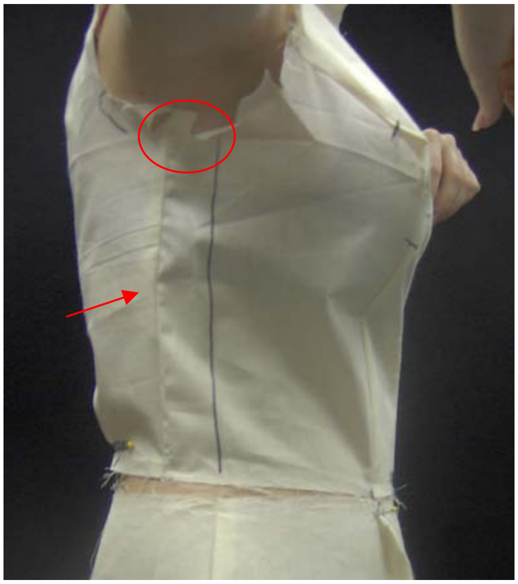

Figure 69. Side seam too far back and armhole too high at side seams.

Another problem was associated with the uptake at the side seam armhole point, which was too loose for 25% of the participants and needed to come in on average 0.38 inches. The side seam also slanted toward the back of the body (see figure 70) for 25% of the participants and on average had to be fixed by adding 1.06 inches to the back side seam waist point and subtracting this amount from the front bodice at the side seam waist point. For one of the participants the side seam was too short at the waist by 0.50 inches. (See appendix E).

Figure 70. Bodice side seam angle incorrect.

Bodice bust darts. For all of the participants the front bodice waist darts and armhole bust darts were too long (see figures 71 and 74) on average by 1.63 inches and 1.13 inches respectively. The majority of participant's, 63%, front waist dart leg positions were too close to the center front of the body (see figure 71). Overall, the dart legs needed to be moved away from the center front of the body on average 0.80 inches. (See appendix E).

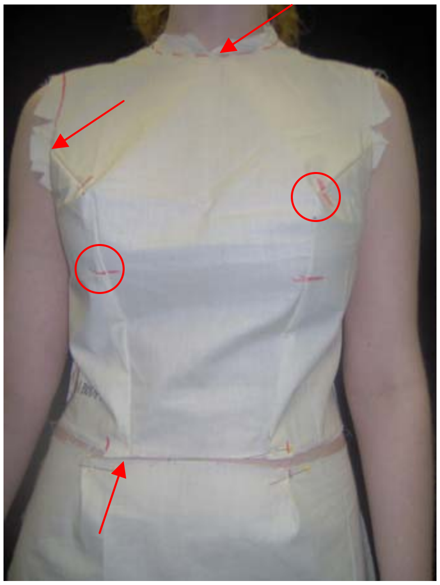

Figure 71. Bust darts too long, waist dart legs too close to center front, neckline too high, and armhole too long at chest level.

The apex of the bodice front waist darts were on average 0.63 inches too close to the center front of the body for 25% of the participants. Twenty-five percent of the participants also had too much uptake in their dart legs (see figure 72) which needed to be let out by 1.25 inches on average. The armhole dart legs were placed too high on the armhole for 25% of the participants and needed to be dropped by 1.75 inches on average. The apex angle of the armhole dart did not need changing for any of the participants. However, similar to the waist dart uptake, the armhole dart had too much uptake for 25% of the participants. It also had too little uptake for one participant. On average the two changes cancelled each other out leaving the need to decrease uptake by 0.08 inches. (See appendix E).

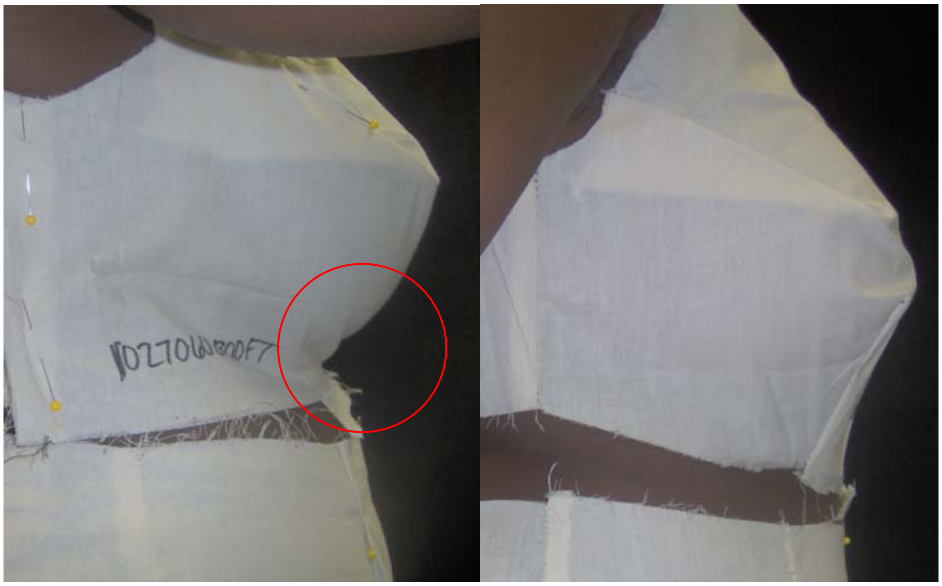

Figure 72. Too much waist dart uptake before and after changes.

Bodice back darts. There were far less changes needed for several participants concerning the bodices back darts as there were for the front bodice darts. The main problem associated with the back bodice darts was the lack of darts at the back waist (see figure 73). Thirty-eight percent of the participants were in need of a back waist dart with an average 0.75 inches of additional uptake needed for each dart. Similar to the front waist darts, but not as common, the length of the back waist dart was too long for 25% of the participants and the back shoulder dart was too long for 38% of the participants. On average the back waist dart had to be shortened by 1.25 inches and the back shoulder dart needed to be shortened by 1.67 inches. Another issue with the back waist dart was that its dart legs were positioned too close to the center back of the garment. On average the dart legs needed to be moved away from the center back 0.57 inches. (See appendix E).

Figure 73. Need for back waist dart before and after.

Bodice armholes. The leveling of the armhole was the major problem that was found when assessing the armhole fit. Fifty percent of the participants' armholes were too long at the front bodice chest level (see figures 71 and 74). This made the arm constricted and unable to move without straining the fabric because it was too long. Overall, the extra fabric present at the front bodices armhole at chest level was removed to shorten the length and deepen the armhole by on average 0.88 inches. Furthermore, the armhole level was too high at the side seam point (see figure 69) for 50% of participants' bodices. However, one participant's armhole was too low at the side seam and needed to be increased in length. On average the length of the side seam was decreased by 0.48 inches at the armhole point. For the back bodice armhole at chest level the length was too short for one participant and needed to be increased by 0.50 inches to cover the back correctly. Armhole gaping was present in 25% of the participants' bodices and required on average 0.44 inches removed at the gaping location to remedy the problem. (See appendix E).

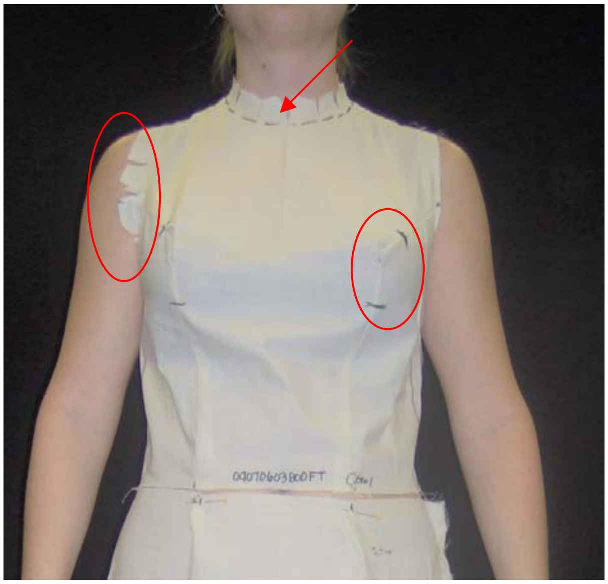

Figure 74. Armhole too long at chest level & bust darts too long.

Number of Bodice Changes

Total changes to bodice. Further assessment of the changes needed for each garment was made to determine the number of changes that were needed by each participant to correct the fit and appearance of the bodice patterns. It was found that the highest percent, 37.5%, of participants had to have 11 changes. Twenty-five percent needed 12 changes and the remainder, 37.5%, needed 13 to 21 changes. On average, 13.13 changes were needed to correct the bodice patterns developed from the NX-12 3D to 2D pattern unwrapping software for each participant. However, this mean score is high due to the one participant that needed 21 bodice changes (see figure 75).

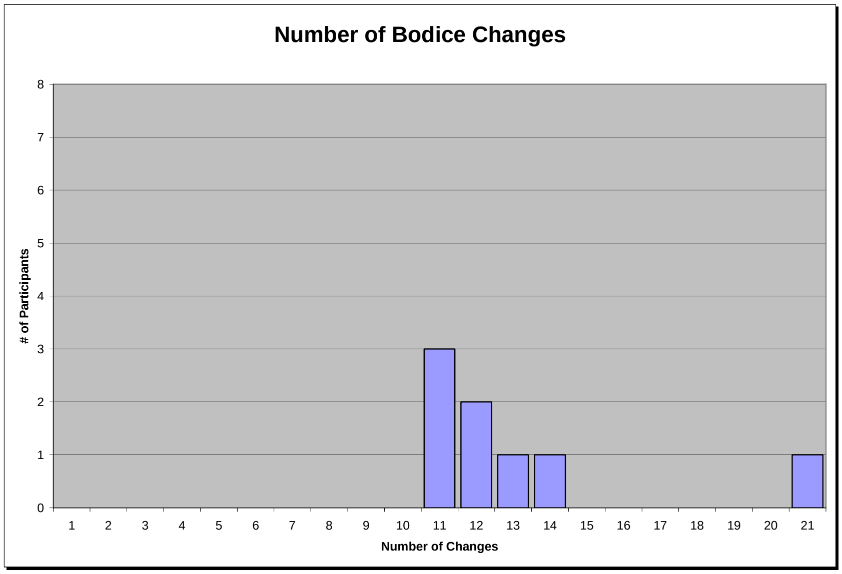

Figure 75. Bodice changes.

Bodice fit changes. The bodice changes were further analyzed to assess the number of fit issues and the number of appearance issues using the variables of fit and appearance explained in chapter two. In this analysis it was found that 37.5% of the participants had 7 changes made to the garment that were done to improve its fit. The average number of changes to improve the fit of the garment was 6.38 out of 20 possible fit changes that could be made to the bodice. Therefore, an average of 31.9% of the possible changes to fit was made to the bodice pattern (see figure 76).

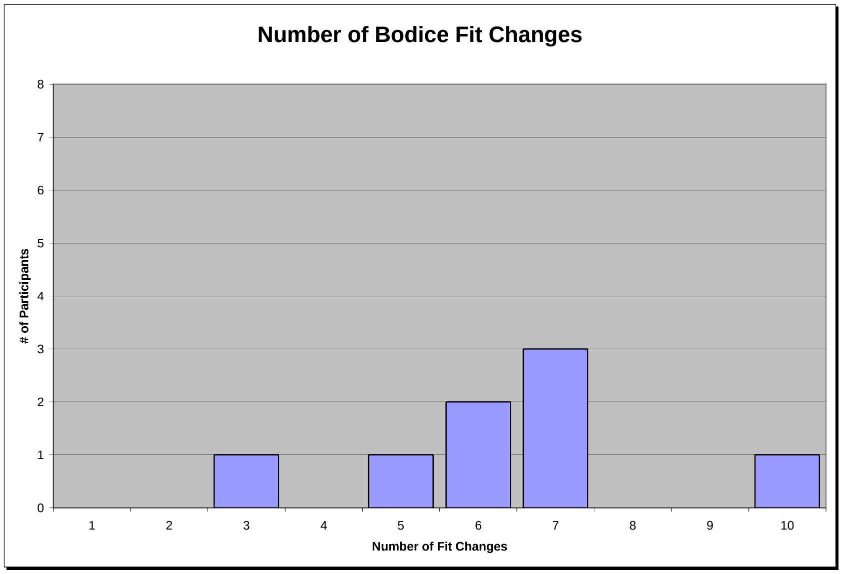

Figure 76. Bodice fit changes.

Bodice appearance changes. The average number of bodice appearance changes needed was 5.25. In total there were 15 appearance changes that could have been made to the bodice pattern. Therefore, 35% of the possible appearance changes to the bodice pattern were made on average. Furthermore, the number of appearance changes needed for the bodice was evenly distributed between 3 to 8 changes (see Figure 77).

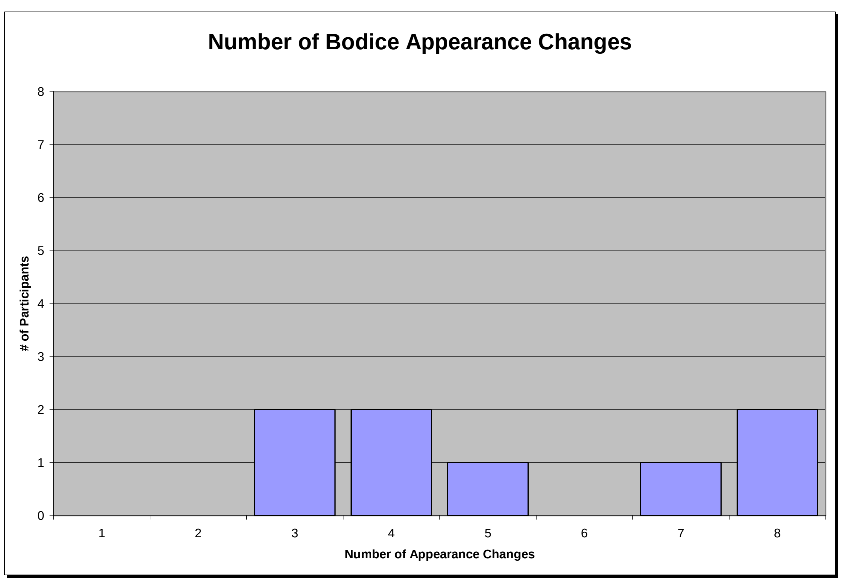

Figure 77. Bodice appearance changes.

Below is a figure illustrating the difference in the bodice pattern before and after fit and appearance changes were made. The white outline of the garment is the altered pattern and the green outline is the original 3D to 2D pattern.

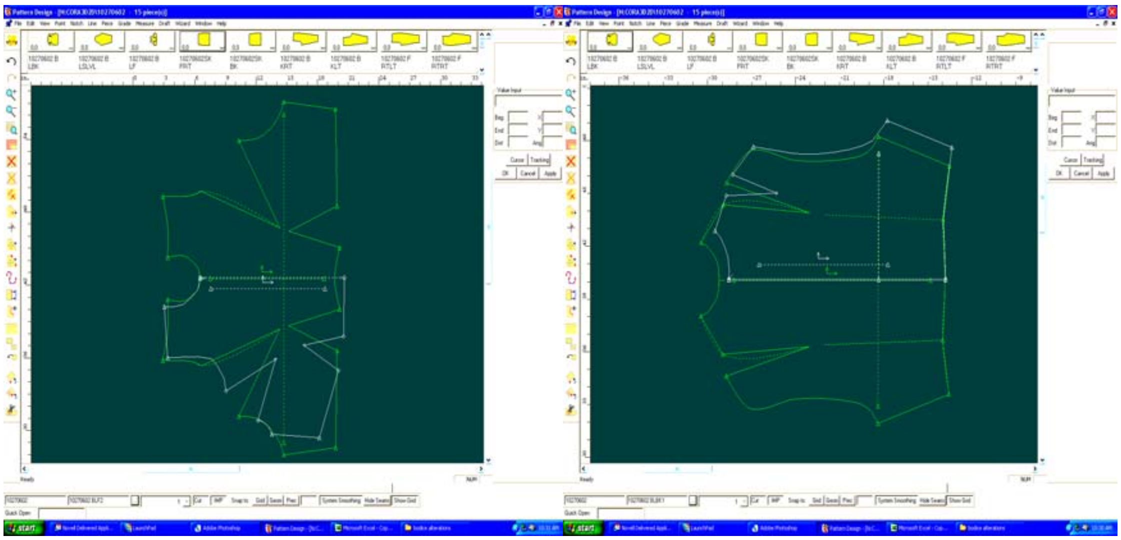

Figure 78. Bodice comparison of initial 2D pattern to altered 2D pattern.

Skirt Fit and Appearance Analysis

Skirt Fit and Appearance Issues

Skirt seams. The side seam position on the skirt patterns created was correct for all but one of the participants. For the one participant the skirts side seam was placed too far back on the body. To correct this issue the side seam was moved forward 0.25 inches. (See appendix E).

Skirt darts. The darts on the skirt patterns mimicked the issues associated with the bodice pattern for a number of participants. Similar to the bodice, the length of the back darts were too long (see figure 79). The back skirt dart length was too long for 86%

of participants which was shortened by 1.96 inches on average. However, opposite from this change the front darts needed to be lengthened for 29% of the participants an average of 2.44 inches. The positioning of the dart legs was incorrect more often for the back dart than the front dart. Seventy-one percent of the participants back dart legs were too far from the center back line of the body (see figure 79), while only 29% of participants front dart legs were to close to the center front of the body. In all, the back dart legs had to be moved toward the center back an average of 1.03 inches and the front dart legs had to be moved toward the center front line an average of 0.47 inches. Similarly, the back and front dart apexes had to be moved the same amount as the dart legs. (See appendix E).

Figure 79. Skirt dart legs and apex positioning incorrect and dart too long.

The uptake for the front dart was too little for 43% of the participants and had to have 0.66 more inches taken out on average for each dart (see figure 80). For the back darts, the uptake was also too little for 14% of participants and had to have 0.50 inches extra taken out of each dart. Furthermore, on average, one extra front dart had to be added to 57% of participants' patterns. (See appendix E).

Figure 80. Skirt front dart uptake before and after.

Skirt ease. The skirt front waist ease needed to be changed for all of the participants in the study. Unlike the front waist, the back waist ease was correct for all of the participants' except one. On average the skirt waist ease was decreased by 1.46 inches. The hip ease for all participants was correct. (See appendix E).

Number of Skirt Changes

Total changes to skirt. Compared to the bodice pattern there were not as many changes that were needed for the skirt pattern overall. The average amount of changes needed per participant was 4.43. The majority of participants, 57.1 needed 5 changes to their patterns. Only 28.6% needed 4 or less (see figure 81).

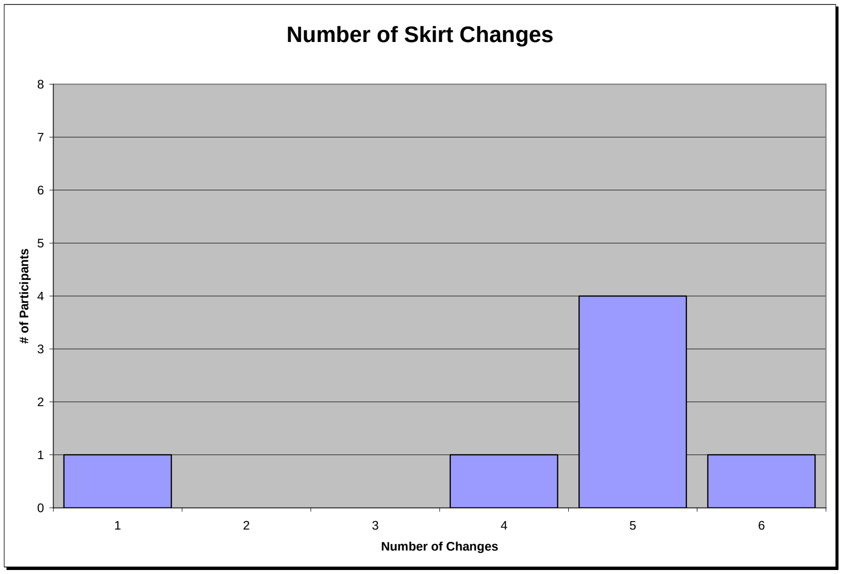

Figure 81. Skirt changes.

Skirt fit changes. The skirt changes were further analyzed to assess the number of fit issues and the number of appearance issues using the variables of fit and appearance explained in the chapter two. Eighty-seven percent of the participants in the study needed just one change to the skirt pattern to correct the fit of the garment. Only two changes were needed for one participant. On average, there was a need for 1.14 changes to fit for the skirt pattern. Consequently, due to there being a total of 5 possible changes for fit to the skirt pattern, an average of 22% of the total possible changes were needed to fit the skirt correctly. (See Figure 82).

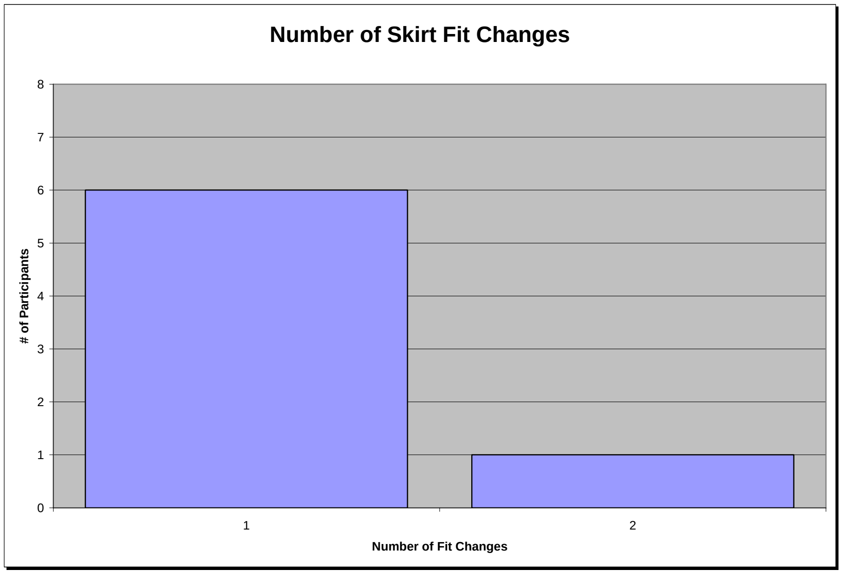

Figure 82. Skirt fit changes.

Skirt appearance changes. For the appearance of the skirt pattern, 42.9% of the participants needed four changes to be made to the pattern. The next highest, 28.6% needed three changes. However, only 14.3% needed no changes to the appearance of the skirt pattern. Overall, an average of 3.29 changes out of 8 total possible changes were needed, which averages to a need for 41.1% of the patterns appearance aspects to be changed. (See Figure 83).

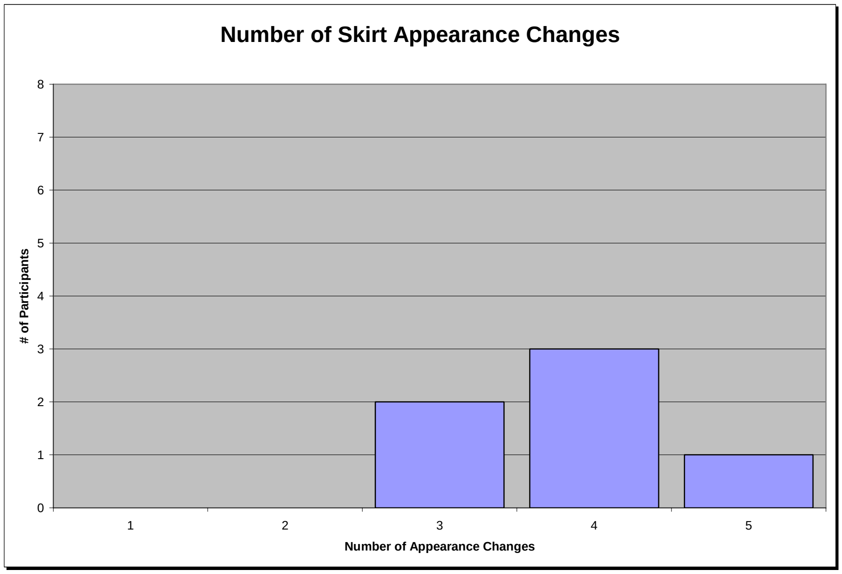

Figure 83. Skirt appearance changes.

Below is a figure illustrating the difference in the skirt pattern before and after fit and appearance changes were made. The patterns on the right are the altered pattern and the patterns on the left are the original 3D to 2D pattern.

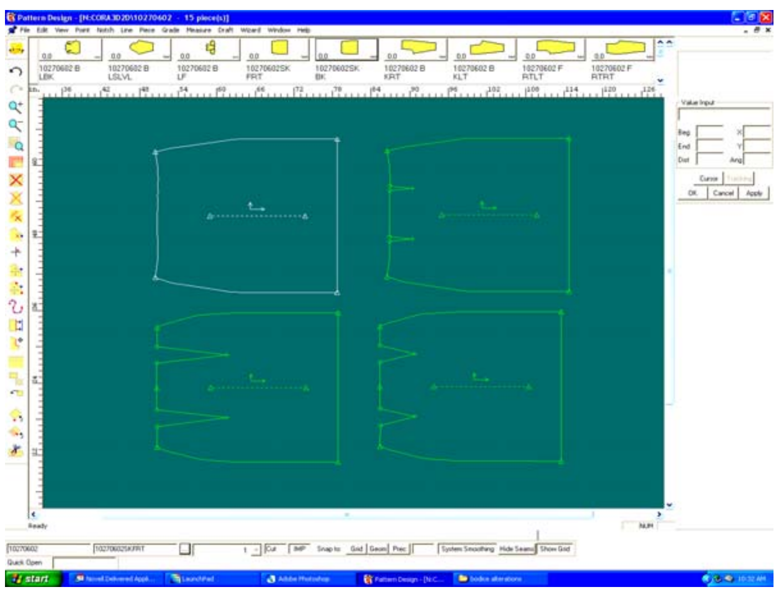

Figure 84. Skirt comparison of initial 2D pattern to altered 2D pattern.

Pant Fit and Appearance Analysis

Pant Fit and Appearance Issues

Pant seams. Overall, there were no changes that were needed across all participants to the pant seams. However, the largest change, evident in 29% of participants' patterns, was that the side seam angle was incorrect (see figure 85). On average, the side seam waist point had to be moved 1.25 inches toward the center front line of the garment. Furthermore, the position of the entire side seam had to be altered in one participant's garment. For this case the side seam had to be moved toward the center front of the body 0.14 inches. Another issue involving 43% of participants was the crotch rise was too low by an average 3 inches. (See figure 86 and appendix E).

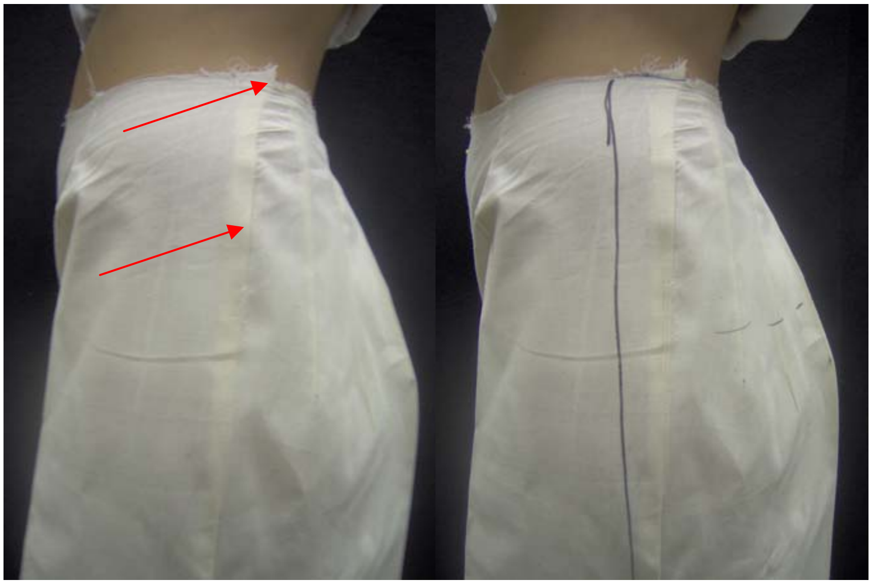

Figure 85. Pant side seam angle incorrect.

Figure 86. Pant crotch seam rise incorrect.

Other changes involved the uptake at the side seam which had to be changed for 29% of participants. Fourteen percent of participants' had too little uptake and 14% had too much uptake. Each of which had to be changed by taking in an average of 0.17 inches. There was also an issue of too little uptake at the center back seam at the waist for one participant, which was corrected by taking in 0.75 inches. The center front and center back waist seam level was too high (see figure 87) for 29% and 14% of participants respectively. On average, the waist seam level had to be decreased by 0.44 inches for center front and 0.50 inches for center back. (See appendix E).

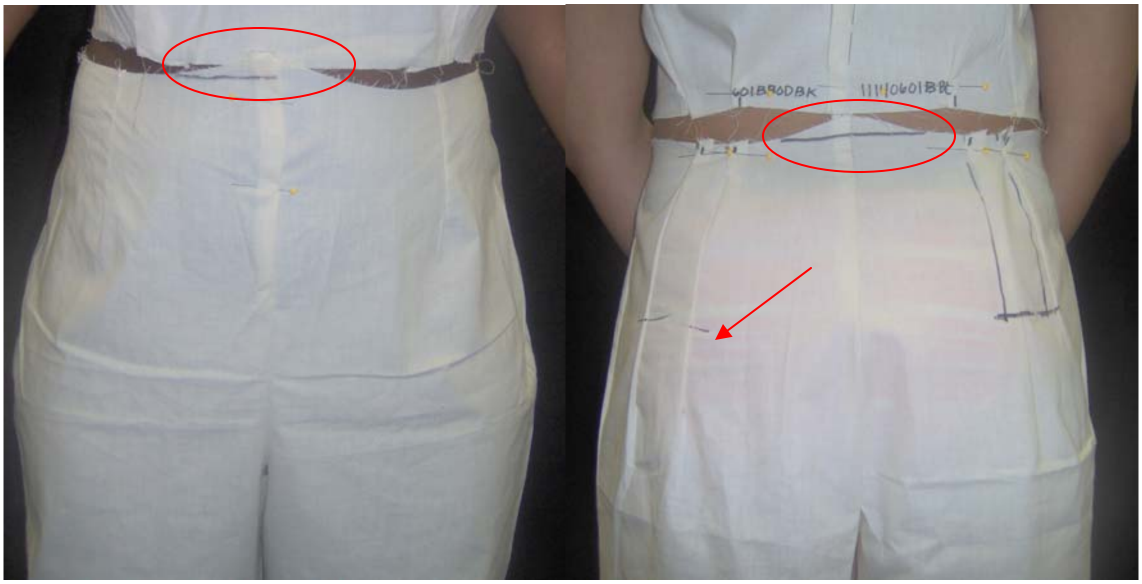

Figure 87. Pant center front and back waist seam level incorrect and back darts too long.

Pant darts. There were a number of common changes needed to correct the pant darts. The most common change was that the back pant dart length was too long (see figures 87, 88 and 90) for 86% of participants' garments. On average, the back pant dart had to be shortened by 1.71 inches. Furthermore, the front dart length needed to be changed for 29% of participants because it was too long by 0.63 inches on average. (See figure 89 and appendix E).

Figure 88. Back pant dart length and pant dart number incorrect.

The position of the front dart legs and apex had to be changed for 57% of the participants. The dart legs and apex alike had to be moved on average 0.95 inches toward the center front of the body because they were originally placed too far from the center front line (see figure 89). The back dart leg position and apex were wrong for 14% of participants. On average the back dart legs and apexes had to be moved toward the center back of the body 0.50 inches. (See appendix E).

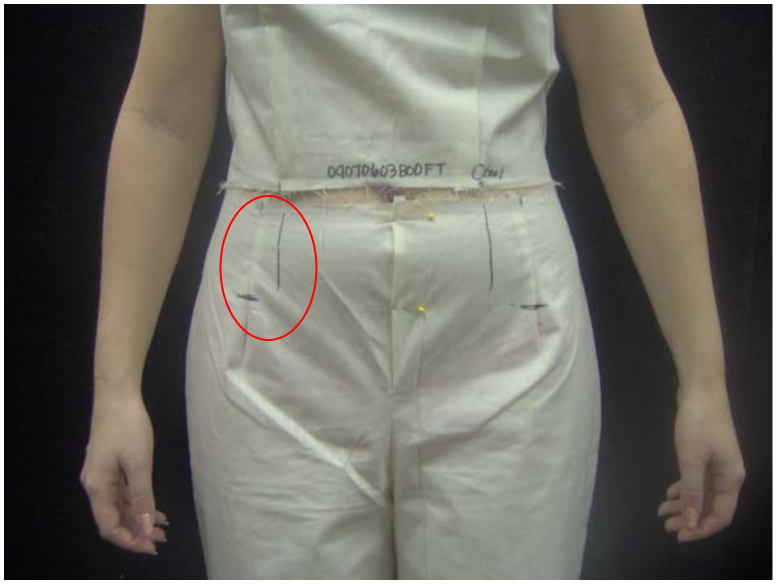

Figure 89. Pant front dart legs and apex positioning incorrect and dart length too long.

When assessing the dart uptake, only 14% of participants needed additional uptake in the front dart as well as 14% for the back dart. Furthermore, an additional 14% needed another dart added to the front panel of the garment. On average the front needed an additional 0.75 inches of uptake for each dart and the back panel needed 0.25 inches of additional uptake for each dart. Another issue that was present concerning the dart was that the back panel had additional darts (more than two) (see figures 88 and 90) for 29% of participants and on average one dart had to be removed. (See appendix E).

Figure 90. Pant dart number incorrect.

Pant hem. The pant hem level was too long for all participants in the study (see figure 91). On average, the pant had to be shortened by 1.68 inches. (See appendix E).

Figure 91. Pant hem length incorrect.

Pant ease. The majority of participants, 43%, had too much ease present at the waist in the pant pattern. However, an additional 29% of participants had too little ease (see figure 92) at the waist. On average, the ease at the waist of the pant had to be taken in 0.47 inches. When assessing the hip ease all participants had 3 inches of ease, 1.75 inches for each pant leg, present and therefore did not need changes to be made. (See appendix E).

Figure 92. Pant ease at waist incorrect.

Number of Pant Changes

Total changes to pant. The majority of participants', 85.8%, had 5 to 8 changes that had to be made to their pant patterns in order for them to be in accordance with the garment evaluation tool. On average, there were 5.86 changes that were needed for each participant's patterns. Only 14.3% of the participants needed 3 changes or less to be made to their pant patterns. (See figure 93).

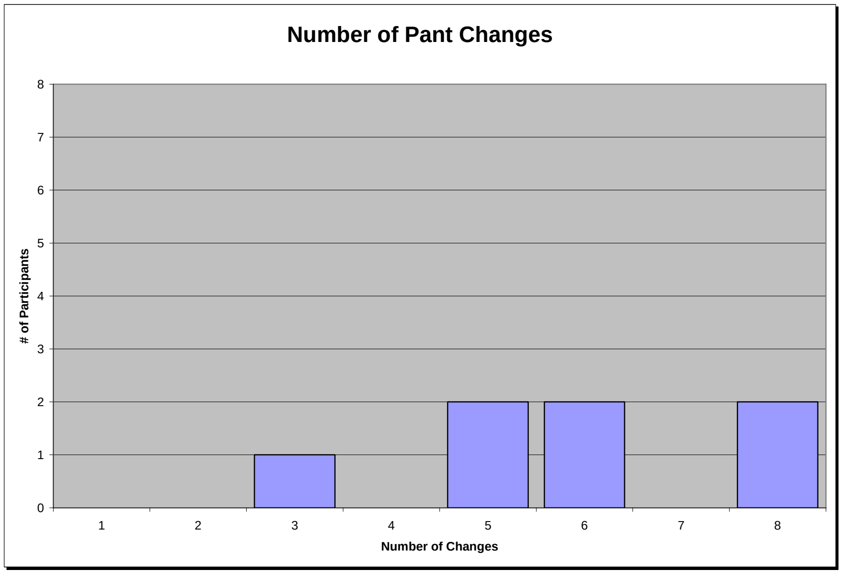

Figure 93. Pant changes.

Pant fit changes. The pant changes were further analyzed to assess the number of fit issues and the number of appearance issues using the variables of fit and appearance explained in chapter two. The highest percent, 42.9%, had four changes that needed to be made to the fit of the pant pattern. However, the average number of changes needed to correct the fit of the pant pattern was 2.86. In total, there were 10 changes that could be made to the pant pattern to correct its fit. Therefore, 28.6% of the possible changes to the fit of the garment were made, on average. (See figure 94).

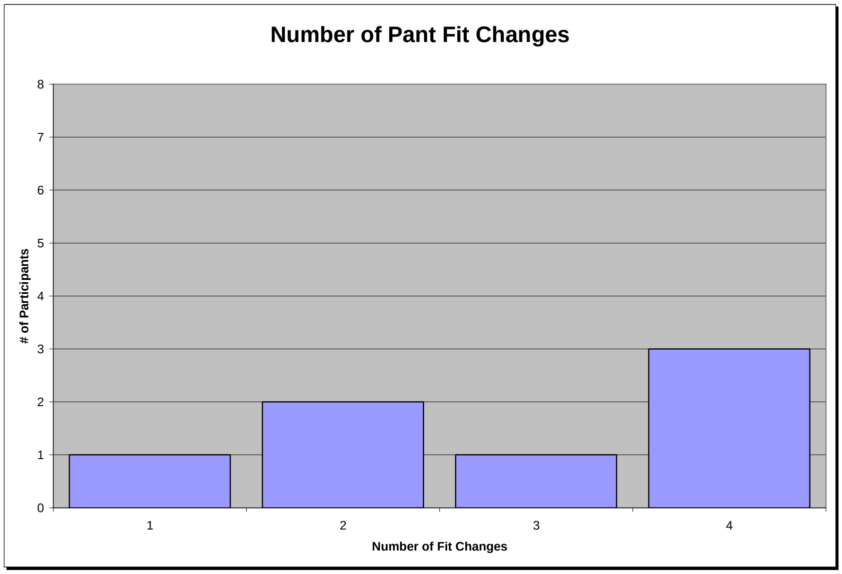

Figure 94. Pant fit changes.

Pant appearance changes. When the appearance changes to the pant pattern were assessed there was found to be a span of changes needed that ranged from 1 to 5. On average, there were 3.14 changes made to the appearance of the pant. Total, there were 9 possible changes that could be made to the change the appearance of the garment. In effect an average of, 34.9% of the total possible changes were made to the pant pattern to correct its appearance. (See figure 95).

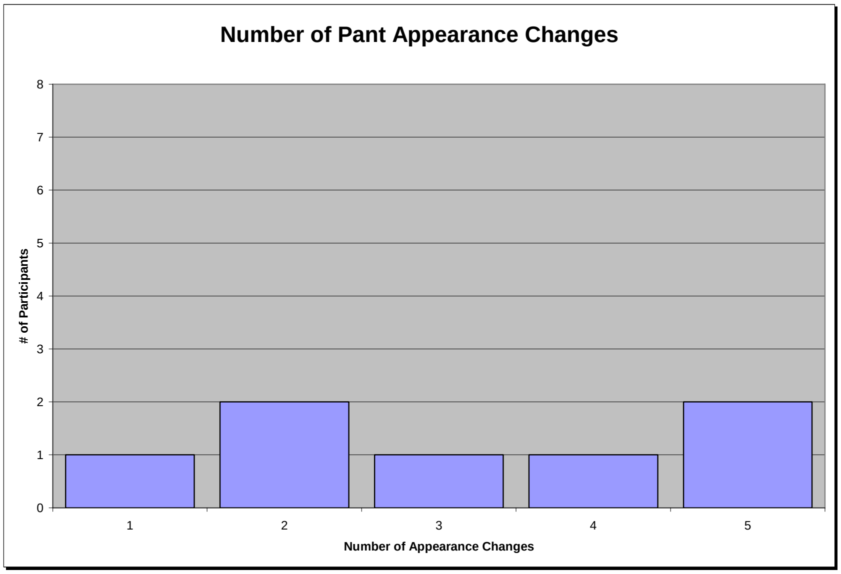

Figure 95. Pant appearance changes.

Below is a figure illustrating the difference in the pant pattern before and after fit and appearance changes were made. The white outline of the garment is the altered pattern and the green outline is the original 3D to 2D pattern.

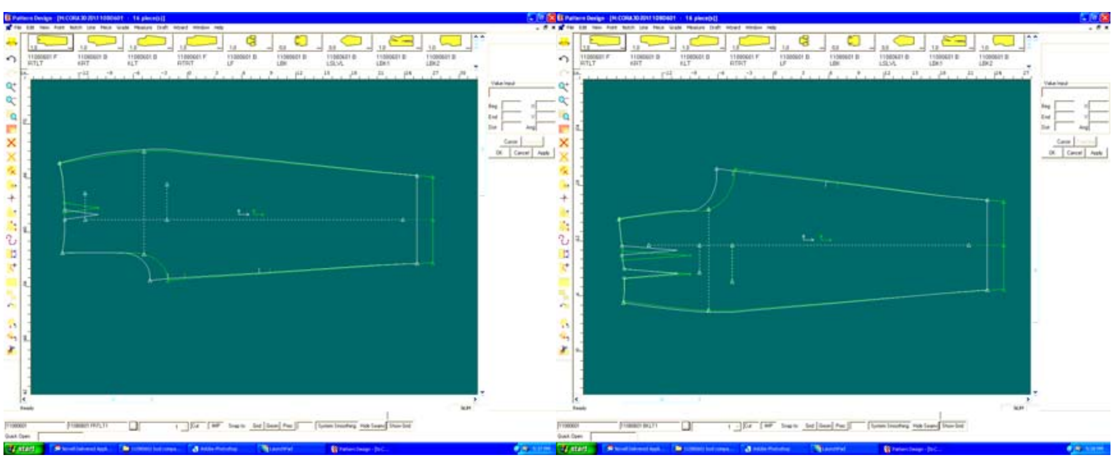

Figure 96. Pant comparison of initial 2D pattern to altered 2D pattern.

Analysis of 3D to 2D Garments by Participant Groups

To answer research question 6, all changes made to the participants' garments were calculated and analyzed to determine if there were any group specific fit and appearance issues that occurred or if the issues that occurred were universal across all participants. The groups of participants were divided by BMI, height, weight, bust measurement, waist measurement, and hip measurement. To determine the relationships between changes made to garments and participant categories each garments objective five's assessments of total changes needed, fit changes needed, and appearance changes needed were compared to each participant category to determine if there was a significant relationship using a one way analysis of variance (ANOVA) test. There was found to be no significant ($p < .05$) relationships between the participant categories and the number of total, fit, and appearance changes needed for the garments.

Participants Fit Evaluation of 3D to 2D Garments

Research objective 7 was answered using the questionnaire on post-fit analysis that was completed by participants after their fit session. For the bodice, participants felt on average that it fit worse to slightly worse than the off-the-rack garments they have tried on (see figure 97). The majority of participants, 71.5%, felt that the bodice fit at least slightly worse than current off-the-rack garments. Only 14.3% of the participants felt that the bodice fit better than traditional off-the-rack apparel. The average rating from the participants for the skirt fit was 3.5, meaning that the participants felt that the skirt fit slightly worse than traditional off the rack garments (see figure 98). Fifty percent of participants felt that the skirt fit at least slightly worse than traditional off-the-rack apparel, while only 33.3% of the participants felt that the skirt fit slightly better. The fit of the pant ranged from participants feeling like they felt extremely better to extremely worse than off-the-rack pants (see figure 99). However, the largest percent, 33.3%, felt like the pant fit better than traditional off-the-rack pants. The average rating for this category was 4.83 or slightly better. The pant overall received the highest rating for fit than any of the other two garments.

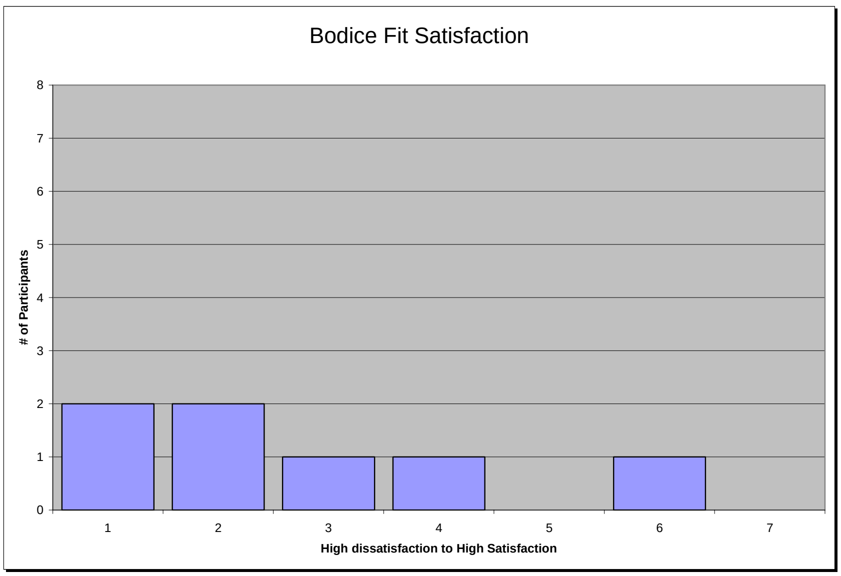

Figure 97. Bodice fit satisfaction.

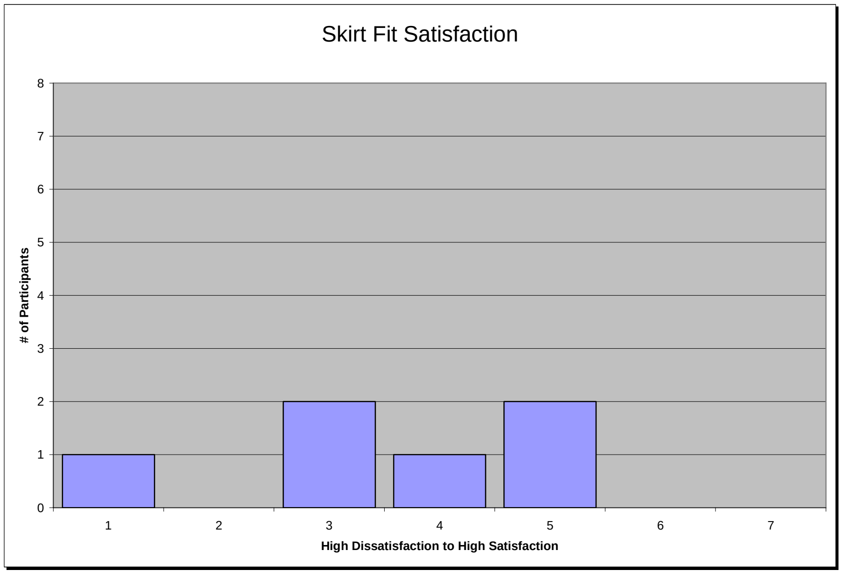

Figure 98. Skirt fit satisfaction.

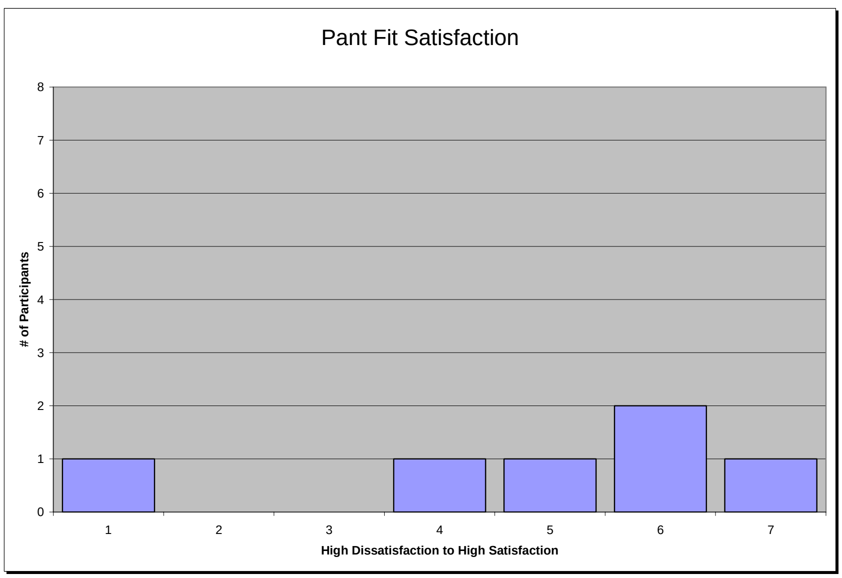

Figure 99. Pant fit satisfaction.

The participants on average were neutral about willingness to pay more for the products they were fitted in. Overall, 44.4% of the participants felt that they would pay more for the products initial fit, while 44.4% felt that they would not. However, more participants felt strongly that they would not pay more for the garments. (See figure 100).

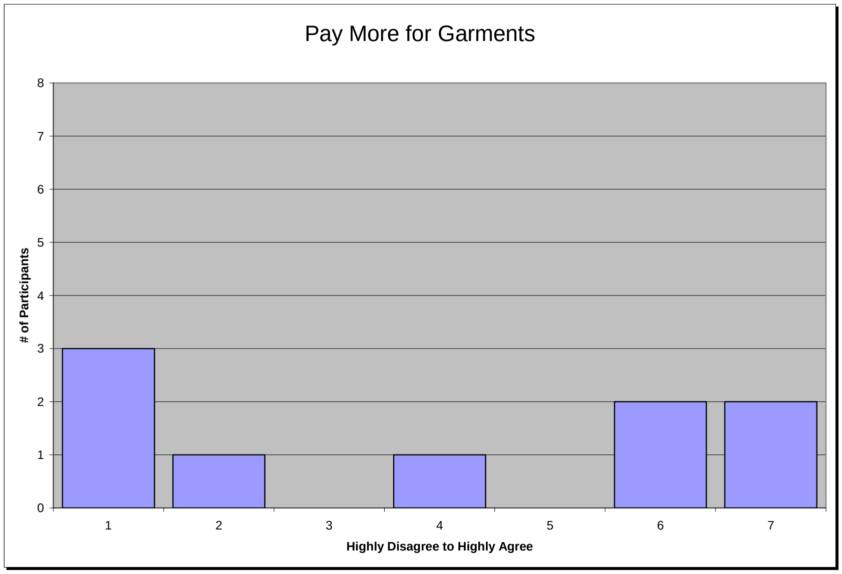

Figure 100. Willingness to pay more for fit of garments.

Chapter 5:

SUMMARY, DISCUSSION, AND RECOMMENDATIONS

Summary of Results

Participant Fit Issues

The study found that the majority of participants have a difficult time finding garments that fit “good”. This was especially true for pants which were determined to be the most difficult garment to find a “good” fit in. The next hardest garment to find a “good” fit in for most of the participants was the bodice which was closely followed by jackets. Off-the-rack skirts however were the easiest for all participants to find a “good” fit according to subject responses.

Participant Assessment of 3D Body Scanning

The study assessed how participants felt about the 3D scanning process that they underwent to get a 3D image of their bodies for 3D to 2D garment extraction. This objective was developed to better understand how the participants rated the process verses the traditional retail experience.

Overall, a high majority of participants agreed that using the 3D scanner was just as comfortable as using a traditional dressing room in a retail store. As an added plus, the participants also on average felt that the process was more exciting, and the majority of the participants felt they would use the 3D scanner again. Furthermore, the majority of participants agreed that they would recommend the 3D scanner to people who had fit issues with the current offering of off-the-rack apparel on the market.

The process of body scanning requires the participant to undress and wear the scanning garments which are close fitting to the body. The scan is executed with the use of cameras and white light, which ultimately produces a 3D image of the participant in the form of a 3D point cloud. This image was given to each participant with their extracted measurements and the process of using the body scanner was analyzed. The variables evaluated by the participants were privacy during the scanning process, confidentiality of the scan image and measurements, sanitation of the scanning garments and scanner itself, health issues from the using the 3D body scanner, and the participants concerns about the 3D point cloud image. It was concluded from the questionnaire that the participants did not have many concerns with the privacy, confidentiality, and image of the point cloud prior to using the scanner. There was however found to be some concern with the sanitation of the scanner for the majority of participants.

The participants who had changes in their rating of these issues after using the scanner once concerns decreased rather than increased. For example, one participant initially rated that privacy during the scanning process was a concern. However, they felt that this concern overall decreased after they used the scanner once.

Analysis of 3D to 2D Process

The process of creating the 2D pattern from participants' 3D scanned point clouds was assessed to determine if there were any issues that occurred on both the individual and collective basis. It was found that the process of pattern extraction for all of the garments worked the majority of the time. The most universal problem that was present across all garments extracted was stray points that on most occasions made the 2D pattern unusable. These stray points were more often noticeable in the 3D extraction of the garment. However, other issues that made the 2D pattern unusable were more noticeable in the 2D pattern rather than in the 3D extraction. Such problems were the incorrect point location on the center line of the body which produced a garment that was off centered and unrecognizable, and missing pattern pieces. These issues seldom occurred and were found for only a small number of participants.

Other more universal problems arose once the garments were imported into the Gerber AccuMark PDS system. These problems included additional lines, incorrect notch attributes, rounded lines, disconnected and connected lines, and dart recognition and evenness. Additional dotted lines that represented seam allowance were added to the bodice and skirt patterns due to the NX-12 systems lack of a parameter that would remove seam allowance. Furthermore, the 3D to 2D garments normally import into Gerber PDS with too many notches. These extra, unnecessary notches needed to be first removed after which the remaining notches categories needed to be changed. Another universal problem was the rounded lines that were present in the bodice and skirt patterns especially at the dart locations. To correct this issue the attribute function was used to convert the lines to straight lines. The program also at times had problems with recognizing darts. In order to fix this problem the intended darts had to be “converted to a dart” in Gerber.

Analysis of 3D to 2D Garments

There were 3 types of garments created from 10 participants 3D point cloud scans. These garments were a bodice, skirt, and pant. Each of these garments was assessed for fit and appearance issues using the garment evaluation tool developed from the literature. All the participants had fit and appearance changes needed. On average, for the bodice there were over thirteen changes needed, over four changes needed for the skirt, and almost six changes needed for the pant. Some of these changes were universal to all participants while others were needed on an individual basses.

Garment fit issues. There were a number of fit issues with the bodice, skirt, and pant patterns developed from the 3D to 2D technology. For the bodice, the first universal fit issue was concerning the shoulder seam length. All of the participants' shoulder lengths were inaccurate either by being too long or too short. The length of the shoulder seams was inaccurate in that it did not start at the side neck point and end where the shoulder and arm connect. The shoulder seam also was not straight, and did not run smoothly across the top of the arm. Rather it was slanted causing an inappropriate fit in one third of participants. Another universal fit issue that occurred in all participant patterns was that the center back or front neckline was too high.

The major fit issue associated with the darts of the bodice was the lack of back waist darts. This only happened for a little over one third of the participants; however the amount of ease removed by adding the dart was on average one and a half inches or three-fourths of an inch per dart. This was also true for the skirt patterns where over half of the participants had issues with missing darts in the front skirt. The skirt patterns ease was altered for all of the participants by either adding a dart or changing the amount of the original darts uptake. On average the waist ease of the skirt pattern was decreased by one and a half inches. The ease for the pant did not have to come in as much as the bodice and skirt patterns. On average, for the majority of participants the pant waist ease was decreased by almost one half inches.

When assessing the bodice armhole fit it was found to be inaccurate for half of the participants. In general, the armhole was too small revealing stress lines. An uneven pant waist seam level was an issue for only one third of participants but impacted the fit of the garment immensely. The center back and center front pant had peeks in these participants' garments that needed to be decreased on average by almost half an inch.

The hem level of the pant was a fit issue present in all participants' pant patterns. In general, the pant hem was too long and had to be decreased in length by over one a half inches on average. Another more universal fit issue that was present in almost half of participants pant patterns was that the crotch rise was too low and had to be brought up by a staggering three inches on average.

Overall, there was on average a need for over six bodice fit changes, a little over one skirt fit changes, and almost three pant fit changes needed. These numbers translate into a need to change on average almost one-third of the bodice, almost a fourth of the skirt, and over a fourth of the pants fit variables to make the garments fit according to the garment evaluation tools specifications.

Garment appearance issues. A number of appearance issues were changed to fit the guidelines set forward in the garment evaluation tool. Over half of the participants' bodice side seam placement was too far back by over one and a half inches on average. This was also true for the pant side seam waist point which was too far back for one third of participants by an average over one inch. The appearance of the front bodice darts was far more inappropriate than the appearance of the back bodice darts. All participants' front bodice dart lengths at the apex were too long by over one inch on average, while only one fourth had this issue with the back bodice darts. This was also true for the majority of participants skirt back darts and pant back darts. However, for the front skirt the darts created were often small and therefore needed to be lengthened rather than shortened more than two inches on average for about one third of participants. The leg positioning of the bodice darts were off for over half of the participants as well. In general, the front and back bodice waist dart legs were too close to the center lines of the garment causing the bodice darts to be slanted inward. In the skirt and pant the opposite was true. The majority of participants back pant and skirt darts legs and apexes, and one third of front skirt darts legs and apexes were placed too far from the center line. Another situation that occurred in one third of participants back darts of the pant pattern was the creation of more than two darts. This appearance issue was changed by eliminating on average one additional dart in order for the garment to appear as the garment evaluation tool stated. Overall, there was on average a need for over five bodice appearance changes, over three skirt appearance changes, and over three pant appearance changes. These numbers translate into a need to change on average over one-third of the bodice, almost half of the skirt, and over one-third of the pants appearance variables to make the garments appearance according to the garment evaluation tool. When assessing if participant characteristics such as height, weight, BMI, and circumferential body measurements influenced the quality of the fit and/or appearance of the 3D to 2D garment there was no significant relationship found.

Participant Evaluation of 3D to 2D Garments

Ultimately the consumer, or in this case the participant, is the final judge of the apparel products fit and appearance. A questionnaire was administered and analyzed to determine how the participants rate the fit of the 3D to 2D garments before they were altered. The average rating by participants for all three garments collectively was that they fit slightly worse than off-the-rack garments. Over three-fourths of participants felt that the bodice fit slightly worse, and half of the participants felt that the skirt fit slightly worse than current off-the-rack garments. However, one-third of the participants rated the skirt as fitting slightly better than off-the-rack skirts. For the pant, the largest percent of participants felt that it fit better than current off-the-rack pants. Overall, the pant received the highest average rating of fit. The next height rating was for the skirt followed by the bodice. Overall, the ratings of the garments somewhat fell in line with the number of changes to fit and appearance that were needed.

Discussion and Recommendations

$[TC]^2$'s NX-12 3D to 2D automatic pattern unwrapping system has the potential to be used in the apparel industry for the development of mass customized apparel products. This is especially true because of its unique ability to take into consideration the individual's body shape and size to produce a garment made specifically for them. Considering the study found that most of the participants have issues with finding garments that fit well, this technology is extremely useful for apparel product development. Furthermore, using the 3D body scanner, an important instrument used in the development of the 3D to 2D pattern, was considered comfortable and exciting. Participants were in general interested in using it again even in a retail setting and most expressed that they would recommend the use of the 3D body scanner to others. Only one slight issue arose regarding the sanitation of the scanner which can be addressed by offering consumers the option to wear new garments, bring their own, or guaranteeing the garments and the scanner are clean. Furthermore, a public dressing room is the traditional method of trying on clothing in a retail environment, which is seldom considered sanitary. Overall, these responses show that participant wise the use of the 3D body scanner was accepted and comfortable on most levels especially after first use. Another positive aspect about the system was that it was not participant category sensitive. This allows for more batch processing and the ability to use one extraction profile for all participants. This in effect means that there are no real barriers to use the 3D scanner to produce 2D patterns.

There are, however, a few issues that need to be addressed about the process and the garments created from the system. Some of these problems are likely to be associated with the individuals point cloud image retrieved from the 3D body scanner which may be the reason why they were not universal across participants. The use of the same extraction profile for each participant allowed for the ability to spot which problems were related to the individual image and which to the extraction profile. Stray points and inaccurate point location of the body's center line made the extraction of garments inaccurate and unusable for a few participants. This is more likely related to the quality of the individuals 3D point cloud image because the problem was not universal, which it would have been if there was a problem with the extraction profile. A method to counteract this issue is to scan the consumer more than once so as to ensure at least one of the scans will be clean and correct and therefore without stray points.

Other more universal problems noticed once the garment was translated into the flat 2D pattern in Gerber PDS could have been avoided by the availability of parameters in the NX-12 3D to 2D system that would have controlled the extraction of the garments. Problems such as rounded lines and dart recognition could be avoided with parameters in the bodice and skirt extraction that allow or do not allow straight and/or curved lines to be present in the garment. Additional lines that were imported with the bodice and skirt patterns could be eliminated by allowing the choice for the seam allowance lines to be the same as the cut lines in the parameters of these two garments similarly to what the pant pattern offers. Also parameters in place in the extraction profiles that selected the imported notch category would eliminate the need for changing the notches once in the PDS system. Furthermore, parameters are needed to assign locations, such as the waist to side seam point, to split lines and dictate where the lines should be merged at all times.

Once the pattern was created into a 3D prototype garment and tested for fit, there were some other noticeable universal problems with the garments found that could have been avoided if there were set parameters for the fit and appearance variables. Parameters need to be in place that control darts in all of the garments. The dart length is the most obvious of the parameters that are necessary. There is a parameter in place to control the dart length of the pant patterns; however there is not one in place for the other garments. Also the number of darts for each garment should be able to be defined. In many cases there was no darts created in the back bodice and front skirt. There were also cases when there were too many darts created in the back pant pattern. All three of the situations could be avoided by offing the user the ability to dictate these characteristics of the darts. The hem level was also found to be a universal issue for all participants. This shows that the hem level is also a parameter that is needed in the pant extraction profile.

If parameters that controlled the dart length, number of darts, and hem level were correctly in place the number of fit and appearance issues with the garments would dramatically decrease by ten variables, five for the bodice, three for the skirt, and two for the pant, thus decreasing the average number of changes needed for each garment. If these parameters were available, companies could pre-set their garment extraction profiles and control these areas of garment fit and appearance. This would ultimately increase efficiently and decreasing the labor and time it takes to create the customized product using this system by eliminating the need to change these problems once in the PDS system.

Other problems that may not be avoidable because they may stem from the use of the 3D point cloud image are related to the side seams, crotch seam, and ease. Missing data because of shading was found to be an issue when using $[TC]^2$'s 3D body scanning technology. Istook and Hwang (2001) found that the armpits and crotch areas were often shaded. This is because the system combines images of the participant and uses those images together to guess what the sides of the body should look like. This may have impacted the side seams, and crotch seam of the 3D to 2D patterns extracted and also explain why the problems associated with these areas were so prevalent in the participants' garments. However, the 3D to 2D system can not correct these problems only accommodate them by taking into account the issues that have arisen with the placement and lengths of these areas of the garments. For example, the crotch seam for a number of the participants' pant patterns were too low and had to be brought up by three inches on average. If the program was written to automatically change the initial crotch point after extraction, the low seam could be fixed. The same is true for the side seams of the garments. The system could be written to alter the initial extraction by moving the total side seams of the bodice and the side seam waist point for the pant forward one point fifty five inches and one inch respectively to eliminate or reduce this problem.

These software changes may not completely eliminate the problems, but it could mitigate them.

Another study conducted at North Carolina State University by Mckinnon and Istook (2002) found that errors can be introduced into the scanned image data through subject movement and positioning. Respiration has been found to significantly affect the scanned data of the participants, which is especially true for the upper torso measurement. The foot position of the participants also significantly affected the scanned data of the participants. This aspect of 3D body scanning is hard to overcome because subjects have to stand with their feet several inches apart, depending on the individual, so that the scanner could acquire an accurate crotch measurement. It was found in Mckinnon and Istook's (2002) study that changes in the foot stance leads to changes in the high hip and thigh circumference measurements. This study ultimately shows that the participants' respiration and position could impact the scan and in effect impact the 3D to 2D garment especially it circumferential measurements. This may explain why the ease at the waist was inappropriate for many participants.

Other problems that may not be affected by the 3D scan or may not be changed via use of parameters were classified as software definition problems. These problems included the proper definition of the neck, the armhole, and the waist. The peaks formed at the waist level were particularly interesting because there was a parameter in place that was supposed to keep this problem from happening. The parameter was set to extract the waist parallel to the ground, and therefore should have not resulted in any curved lines. This anomaly could only be classified as a software problem. Furthermore, the neck and armhole are yet another issue. The neckline was created too high and small for the majority of participants. This was also the case for the armhole which was too small as well. To correct this problem the neckline and armhole must be defined more accurately by the software. Some scanners use marking devices to tell the system where the extremities begin and end (see figure 16). However this is not the case for the $[TC]^2$ 3D body scanner. Therefore, a method must be developed to define the location of the armhole at the chest width as well as define the beginning of the neck in both the front and back of the body.

Overall, the pants were considered the only garment that had an average rating by the participants as fitting better than off-the-rack garments offered. This may be because there are more parameters in place that dictate the extraction of the pant pattern than in the other garments.

Recommendations for future evaluations of the 3D to 2D pattern unwrapping system would be as follows:

1. Test the software after new parameters have been added to the system
2. Test the software using a larger more heterogeneous sample size
3. Test the software using more than one 3D body scanning system

Ultimately, with subtle changes in the software and the addition of parameters, the NX-12 3D to 2D automatic pattern unwrapping software system could be ready for implementation into the textile and apparel industry.

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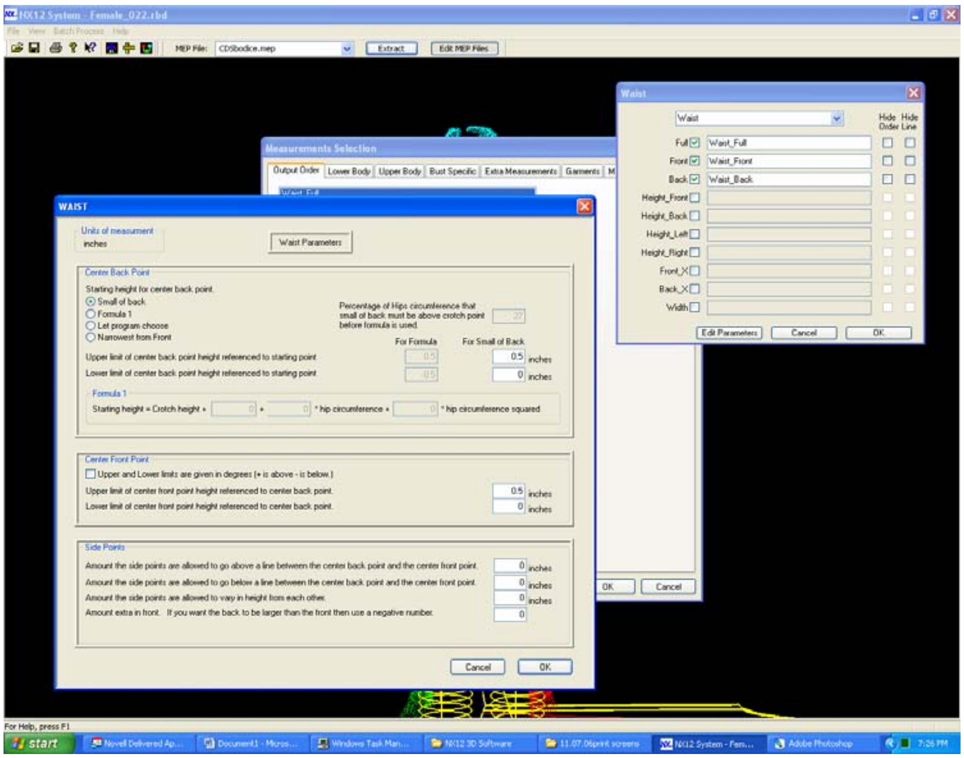
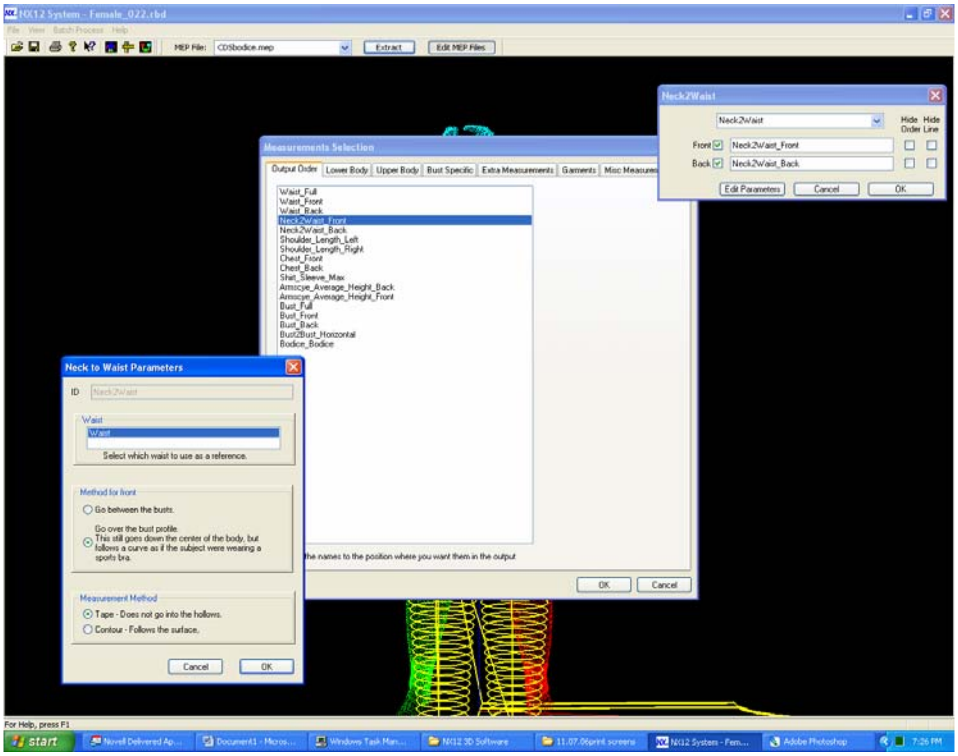
APPENDICES

APPENDIX A: NX-12 Parameters

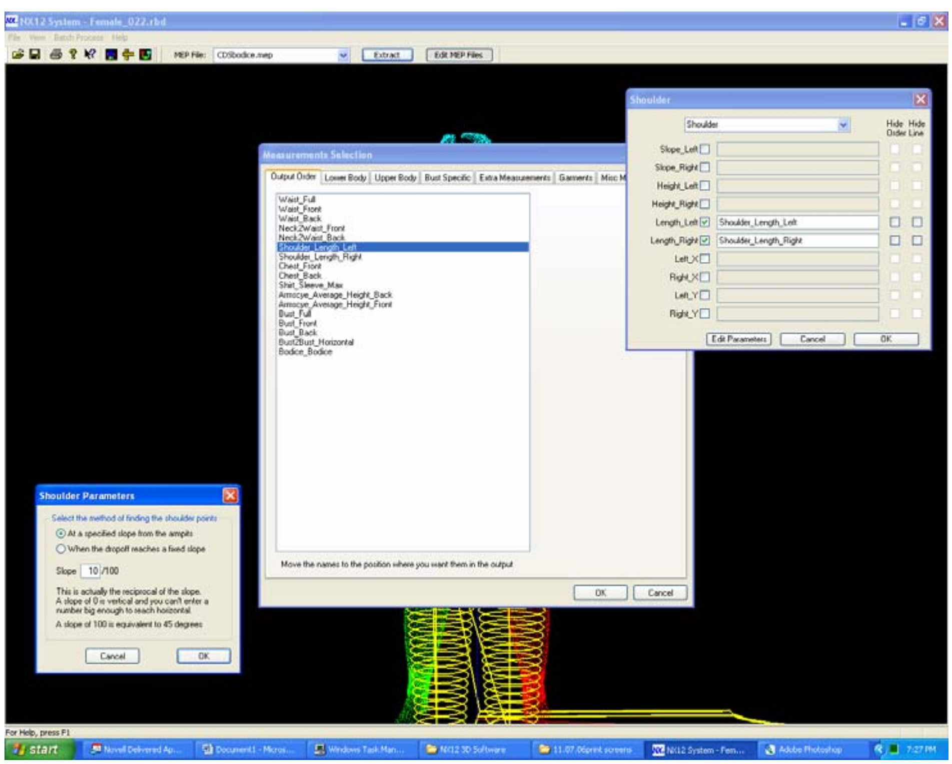
Bodice Waist: Parameter for Bodice Waist Circumference



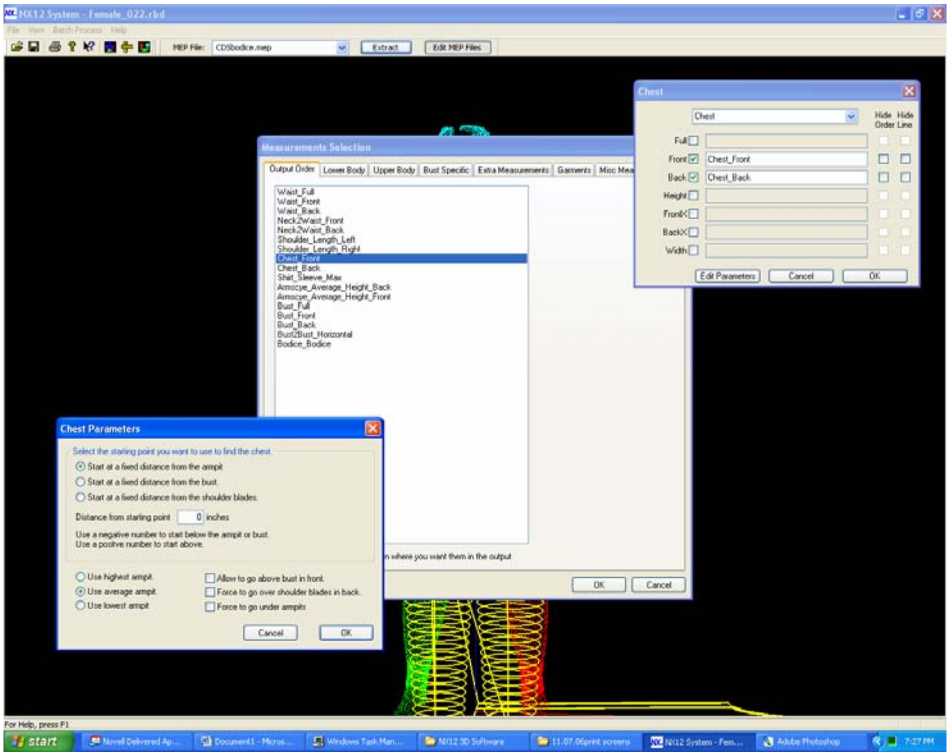
Bodice Neck to Waist Length: Parameter for Bodice Neck to Waist Length



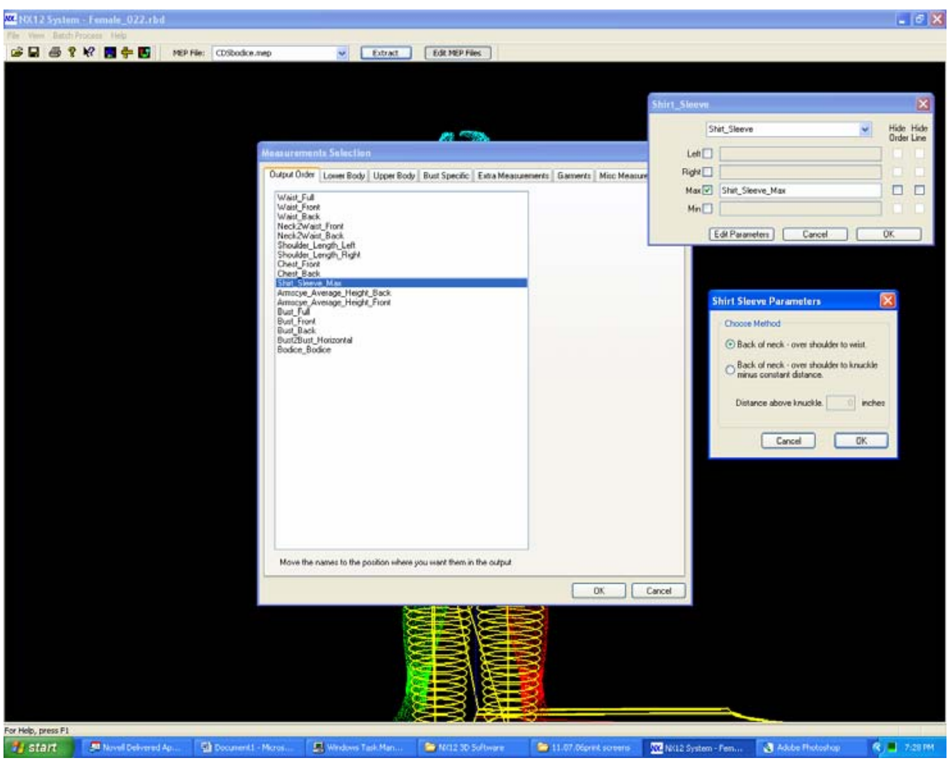
Bodice Shoulder Length: Parameter for Bodice Shoulder Length



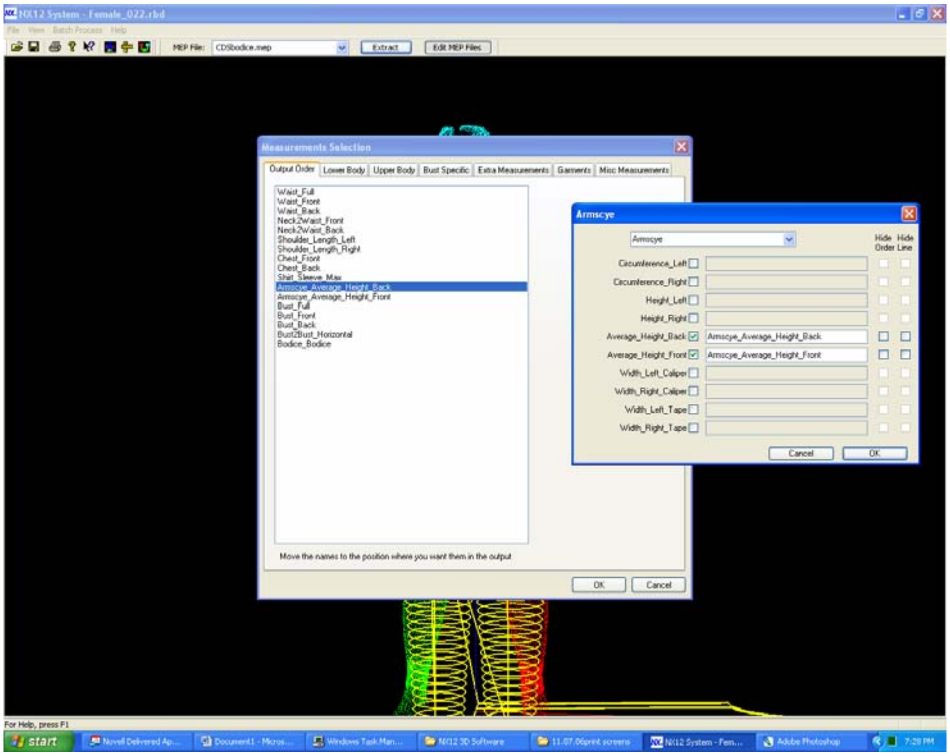
Bodice Chest: Parameter for Bodice Chest Circumference



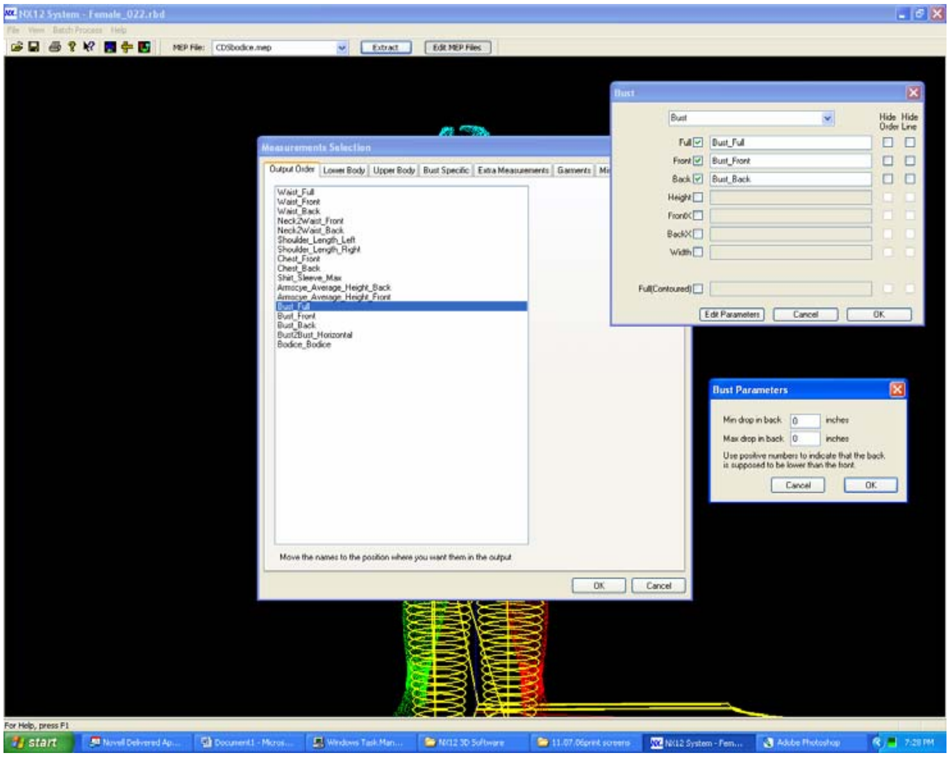
Sleeve Length: Parameter for Sleeve Length



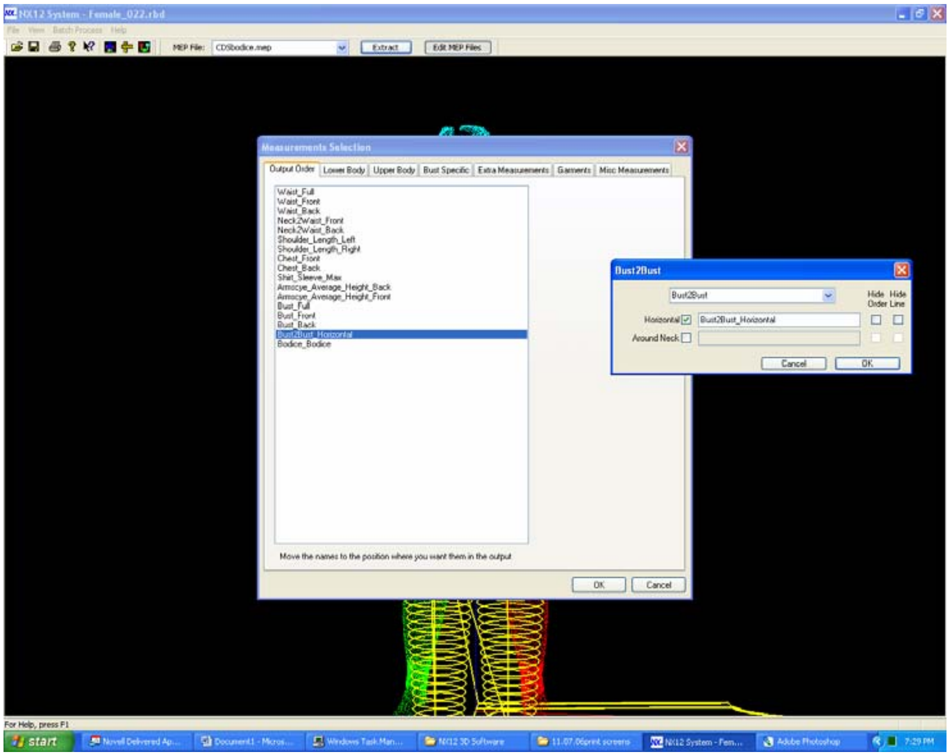
Armhole Height: Parameter for Bodice Armhole Height



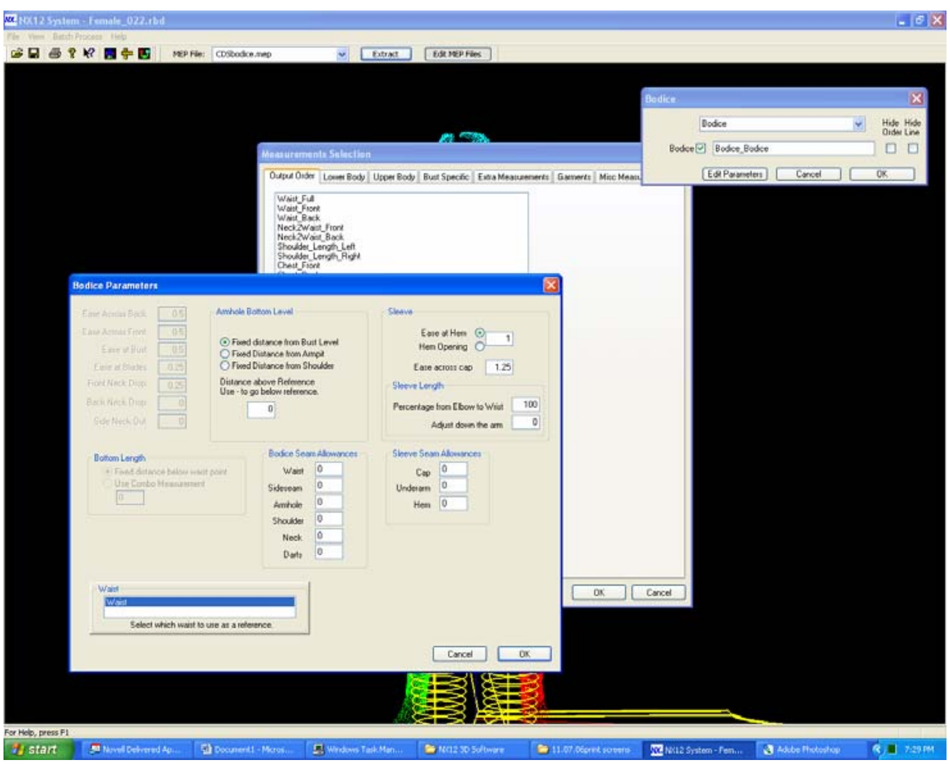
Bodice Bust: Parameter for Bodice Bust Circumference



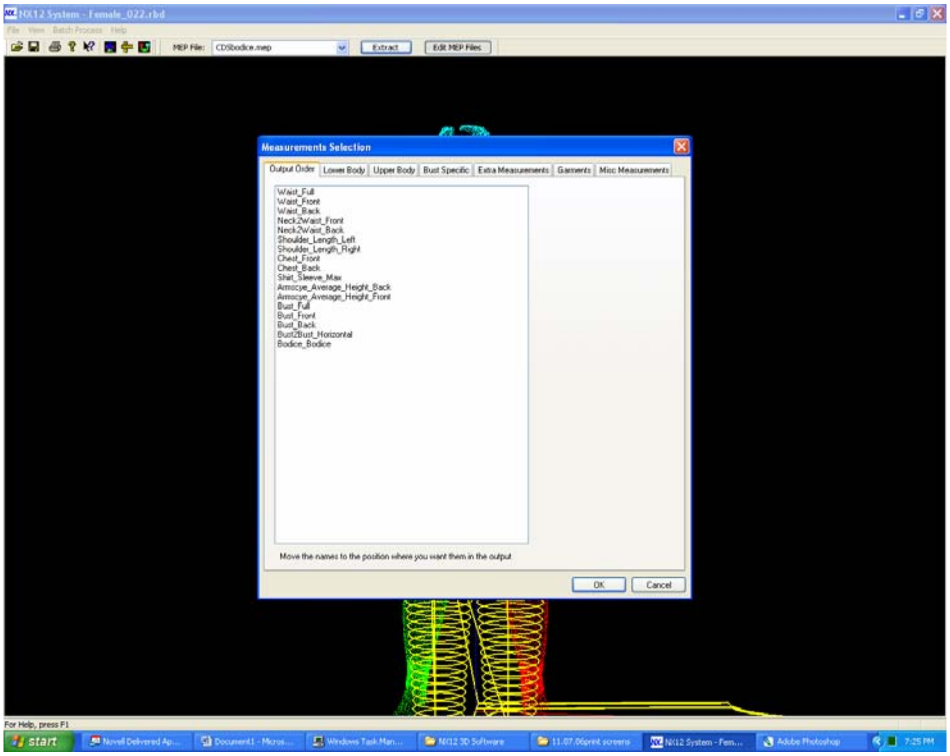
Bodice Bust to Bust: Parameter for Bodice Bust Point to Bust Point



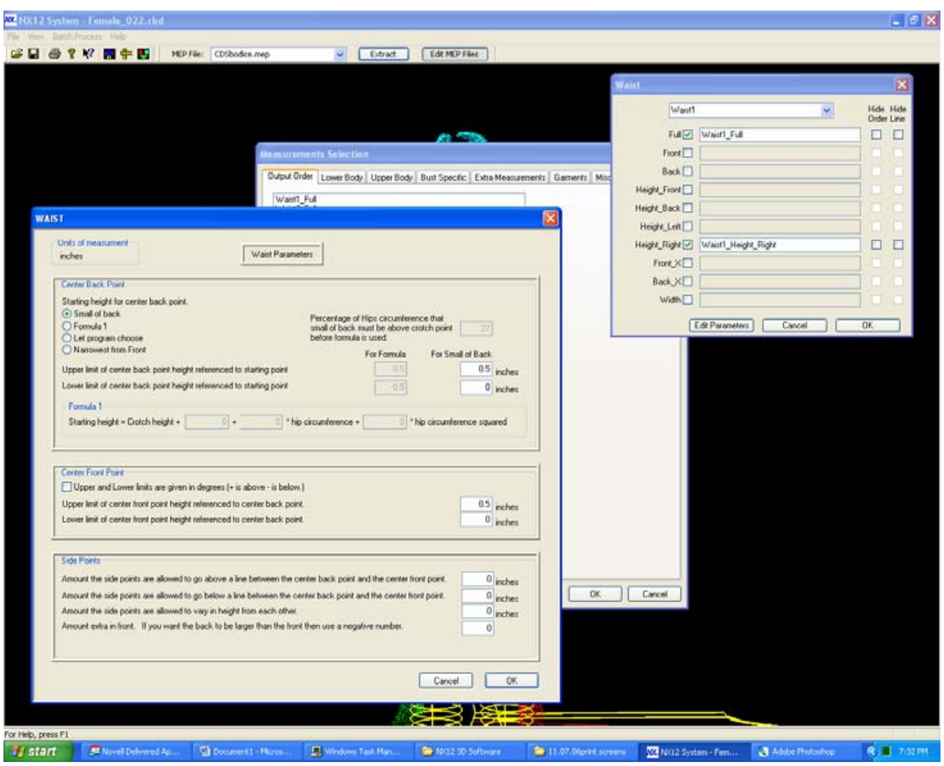
Bodice Parameters: Parameters for Bodice



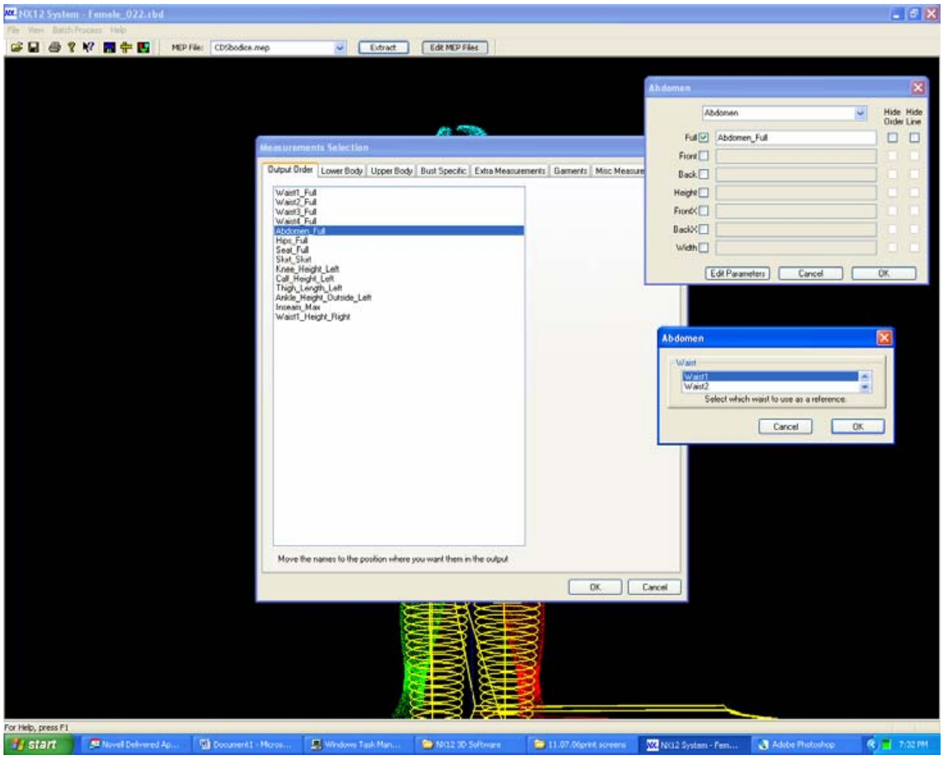
Bodice Extractions: Bodice Extraction Profile Parameters



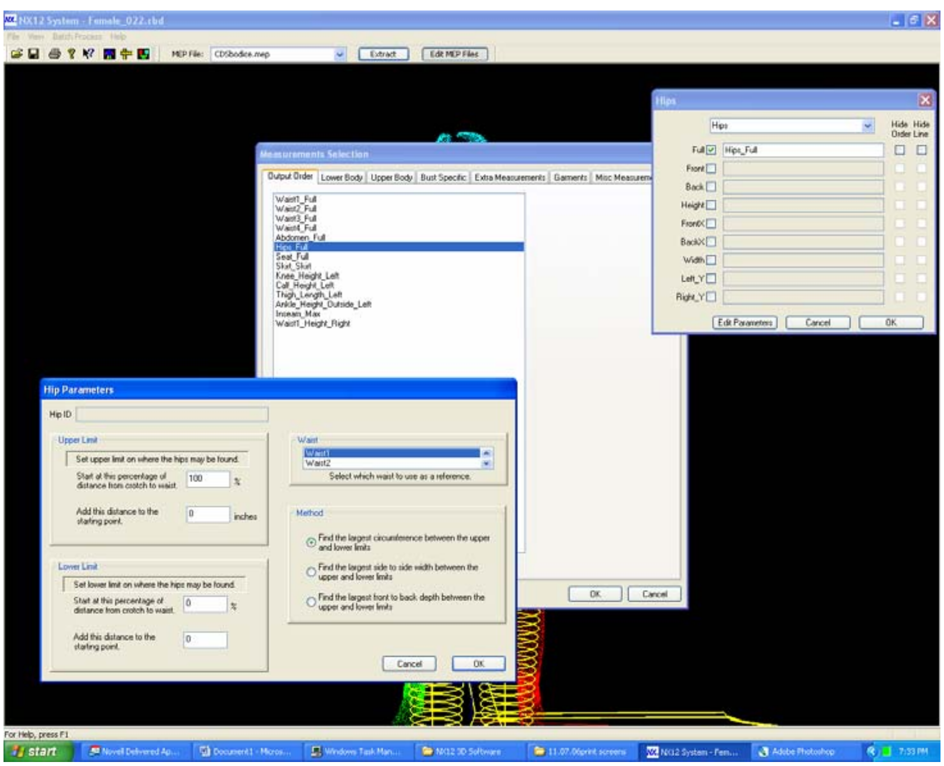
Skirt Waist: Parameter for Skirt Waist Circumference



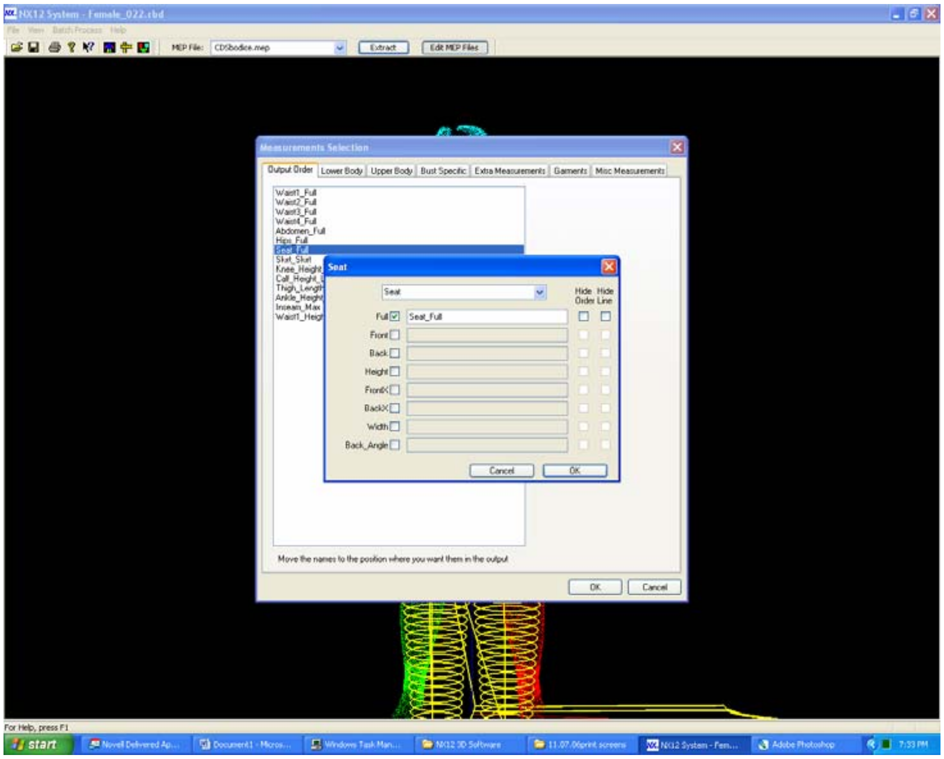
Skirt Abdomen: Parameter for Skirt Abdomen Circumference



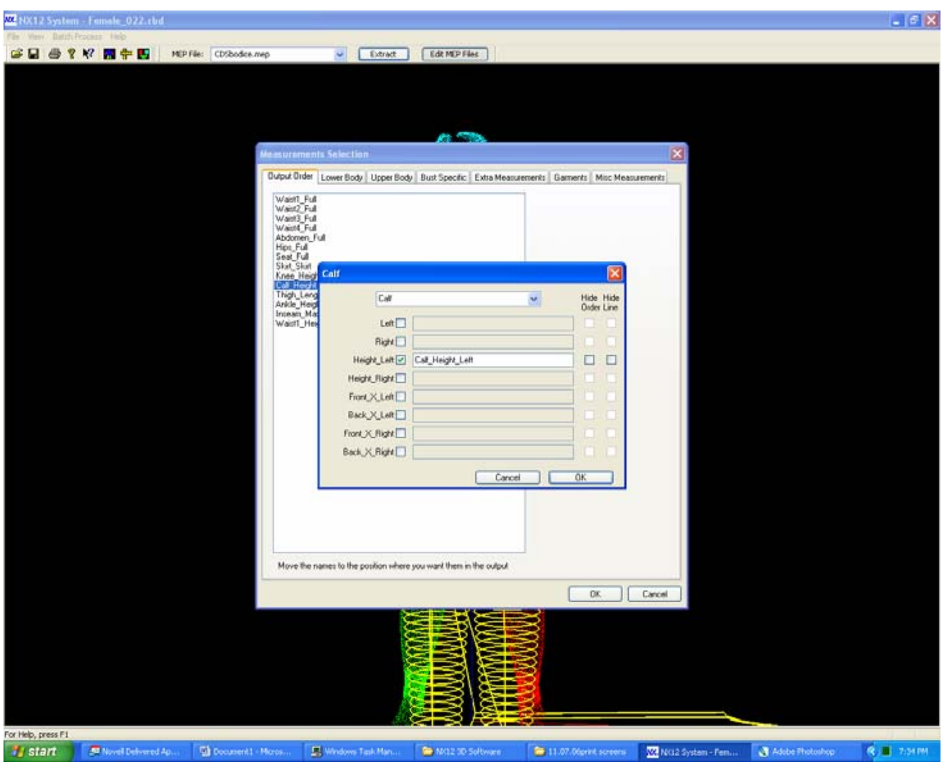
Skirt Hip: Parameter for Skirt Hip Circumference



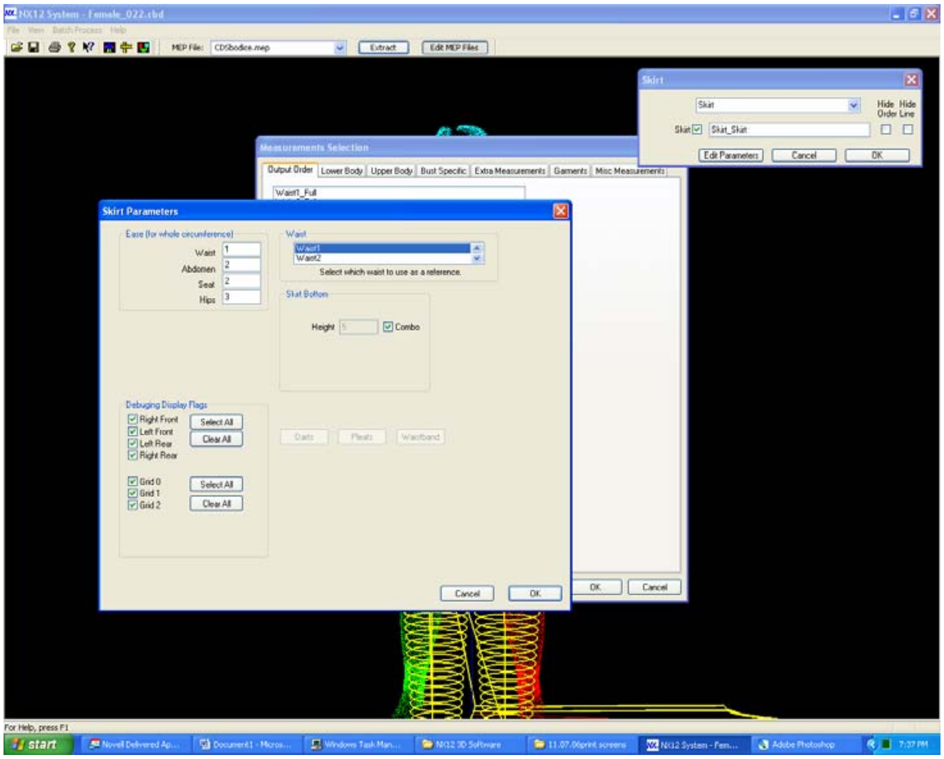
Skirt Seat: Parameter for Skirt Seat Circumference



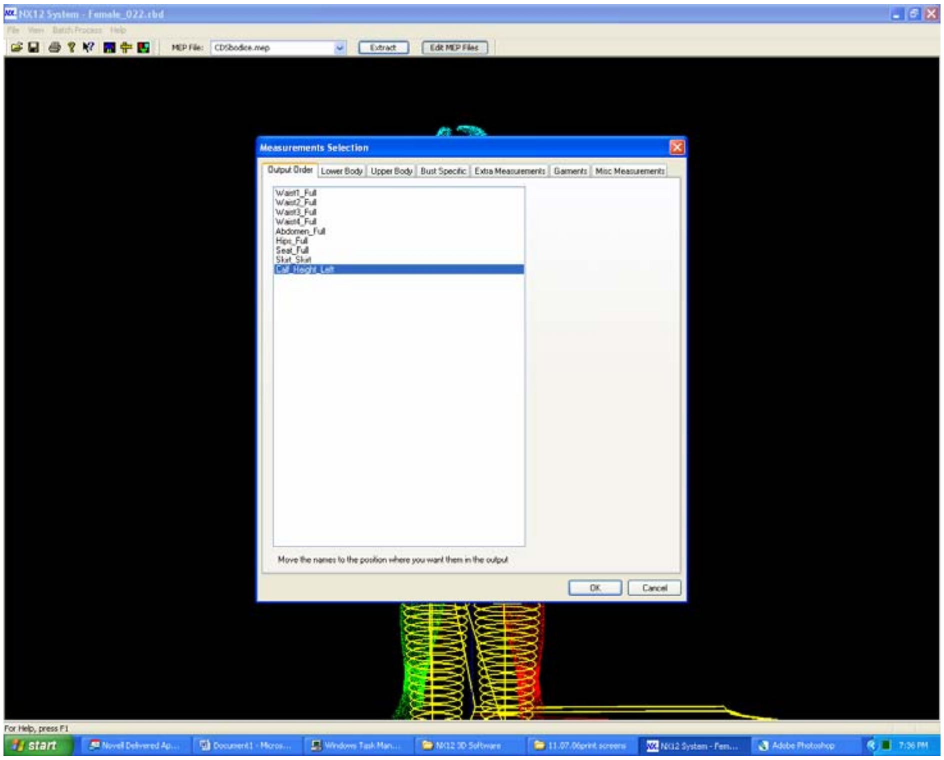
Skirt Calf Height: Parameter for Skirt Calf Height



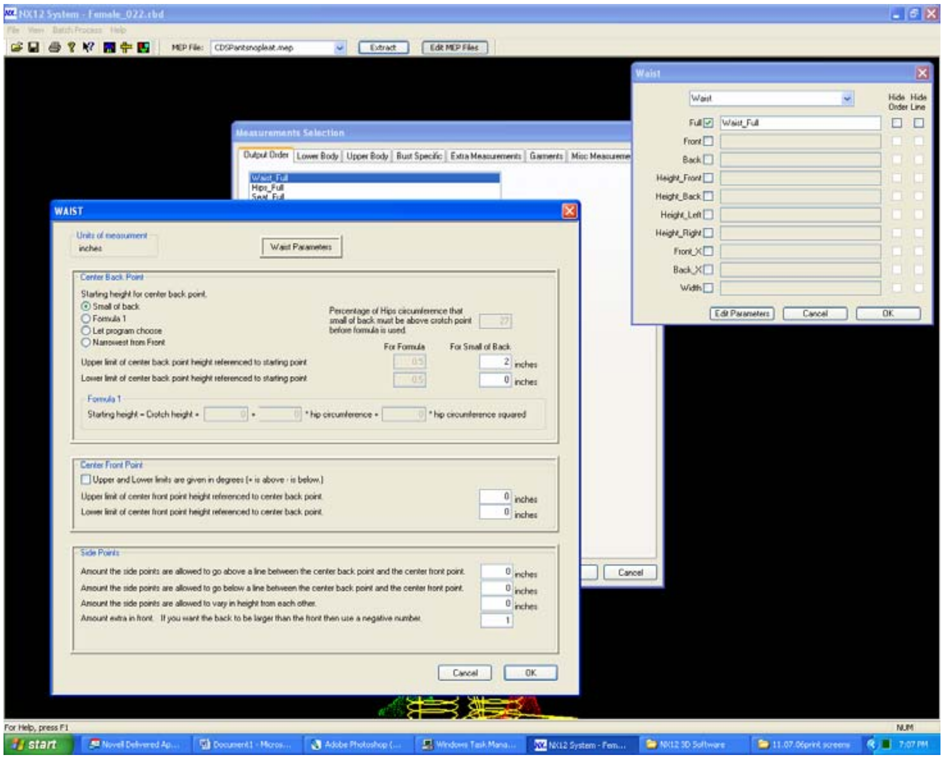
Skirt Parameter: Parameter for Skirt



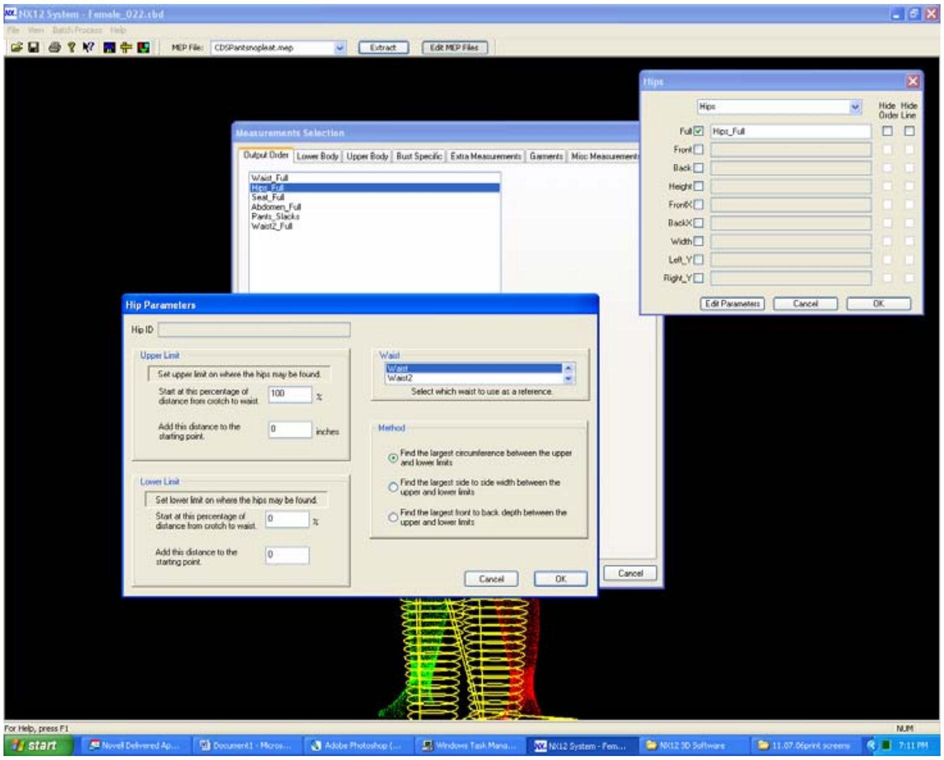
Skirt Extractions: Skirt Extraction Profile Parameters



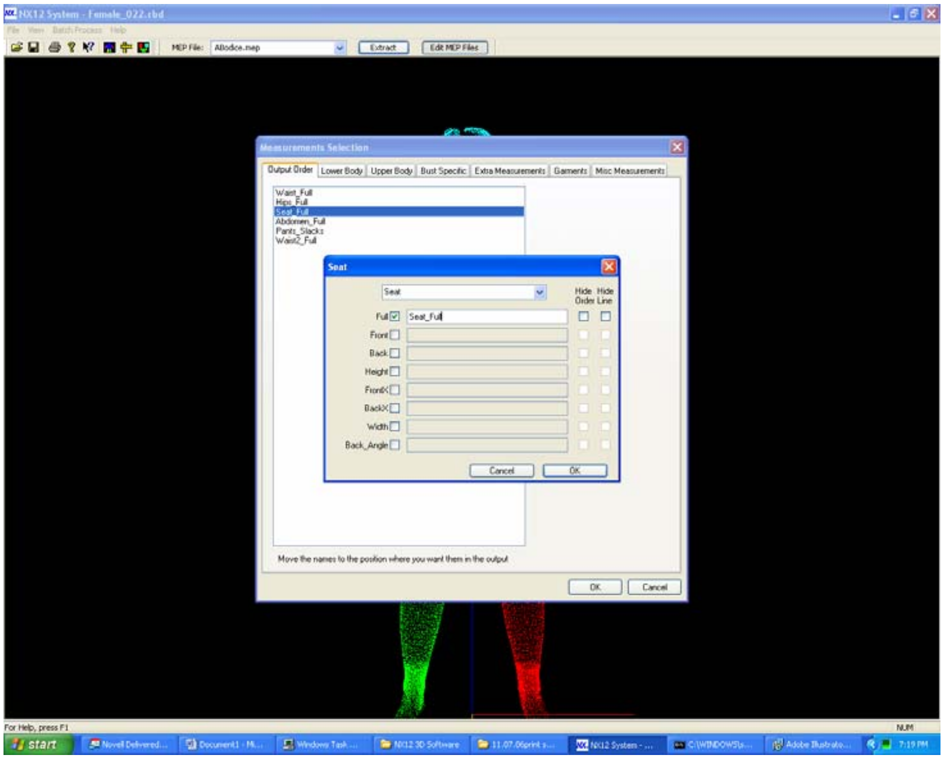
Pant Waist: Parameter for Pant Waist Circumference



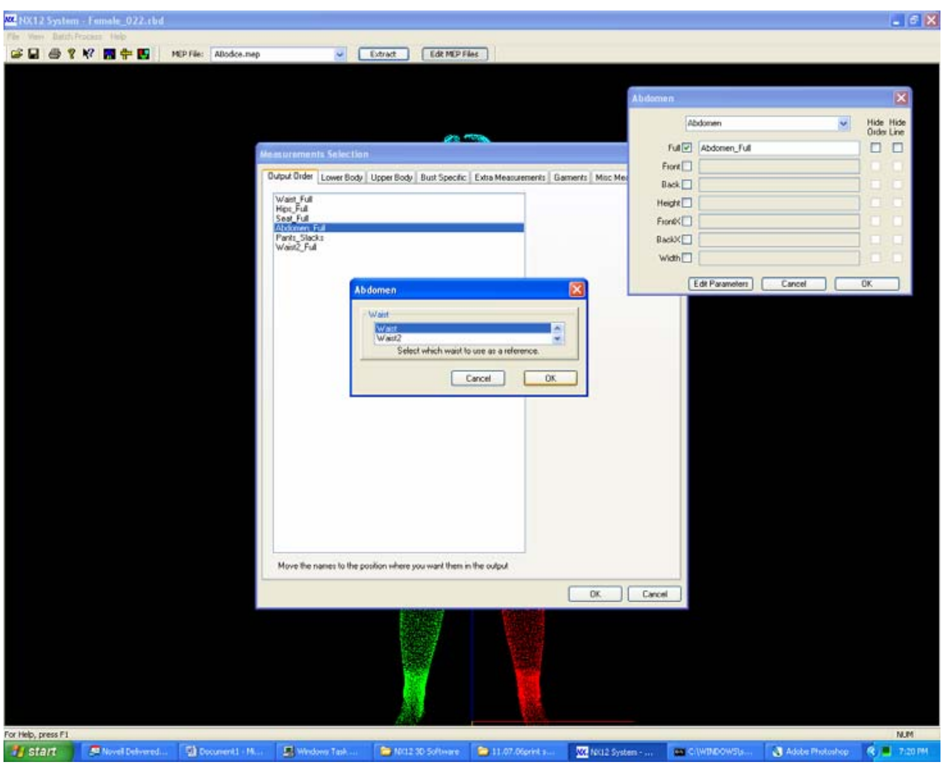
Pant Hip: Parameter for Pant Hip Circumference



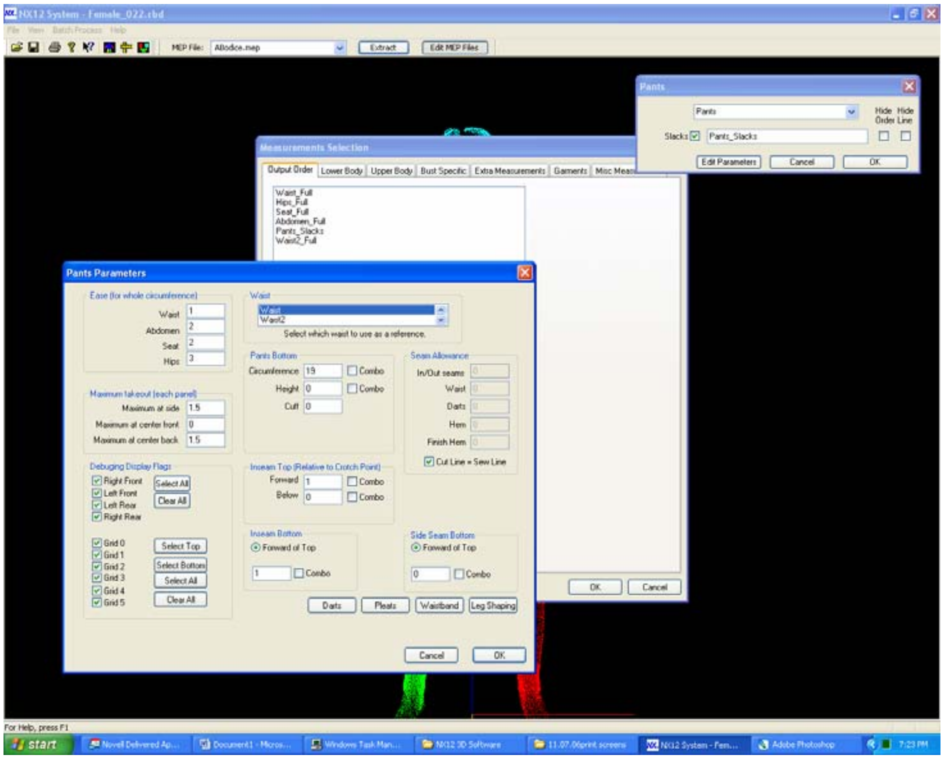
Pant Seat: Parameter for Pant Seat Circumference



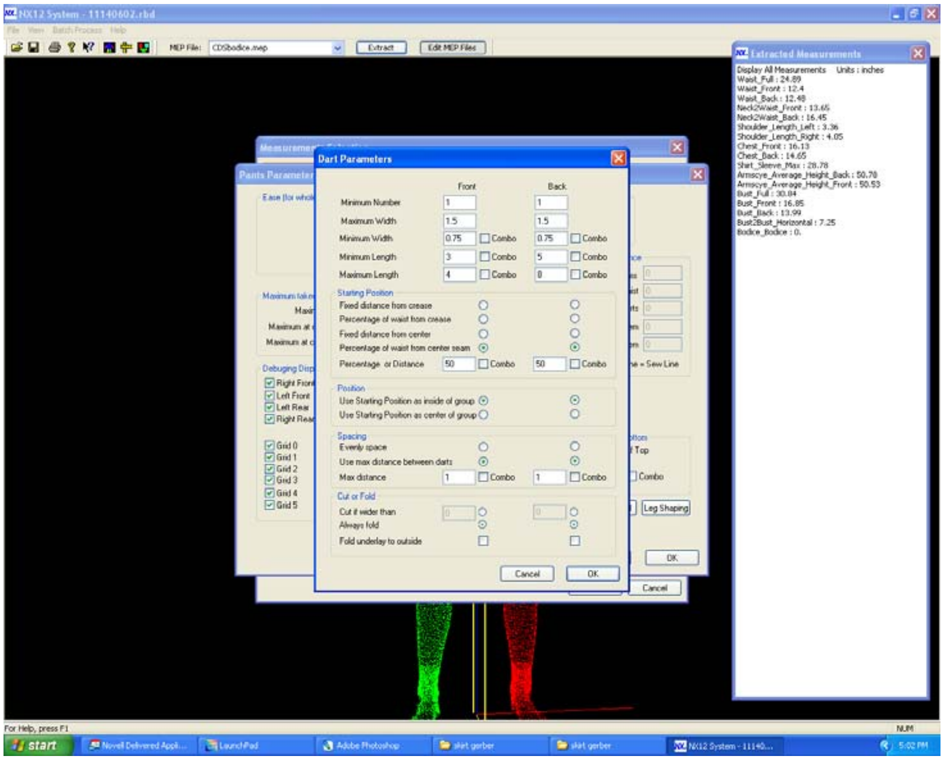
Pant Abdomen: Parameter for Pant Abdomen Circumference



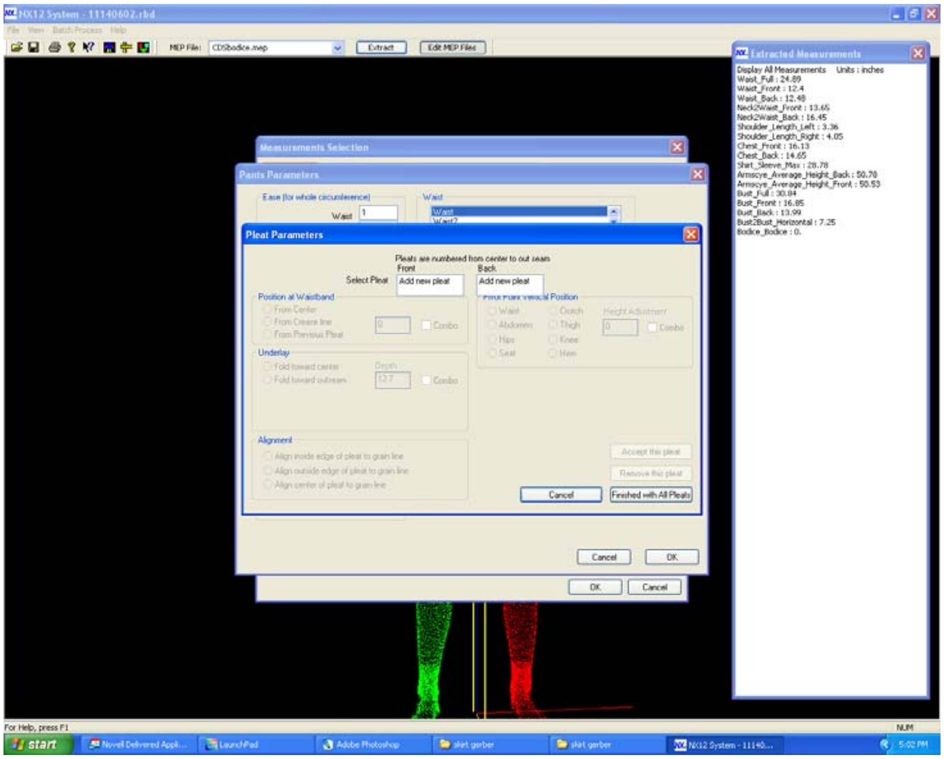
Pant Parameter: Parameter for Pant



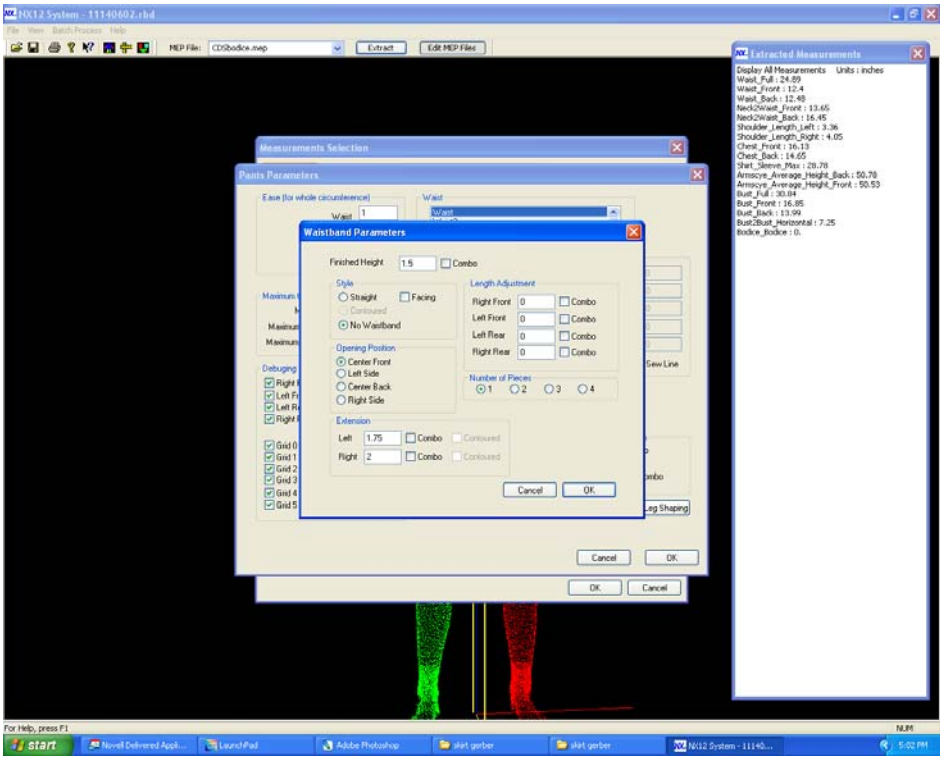
Pant Darts: Parameter for Pant Darts



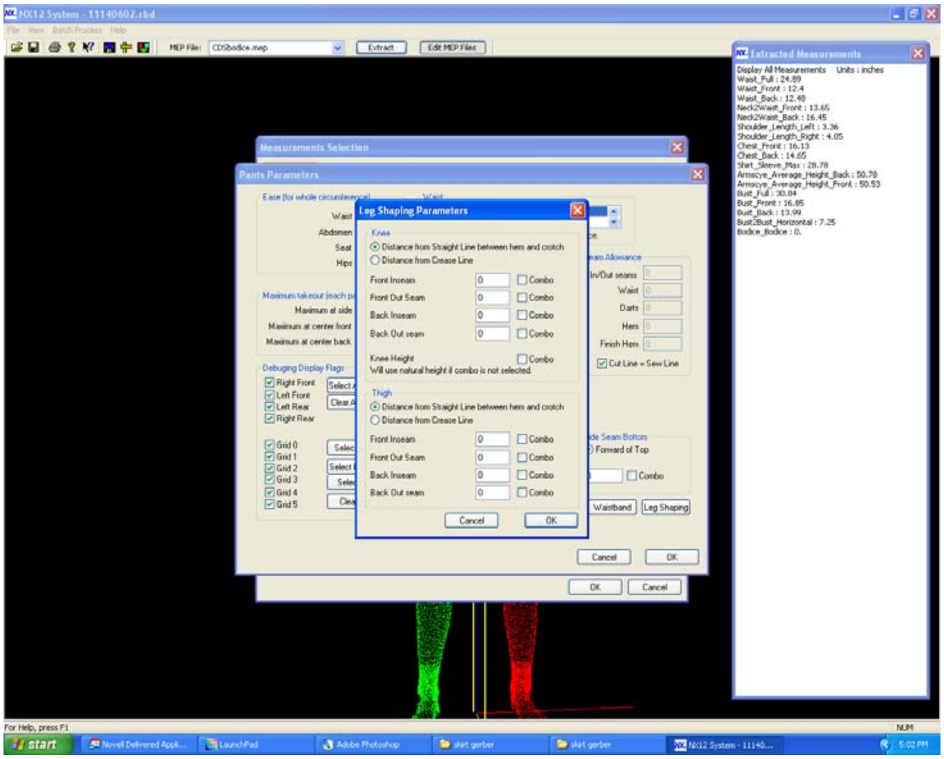
Pant Pleat: Parameter for Pant Pleats



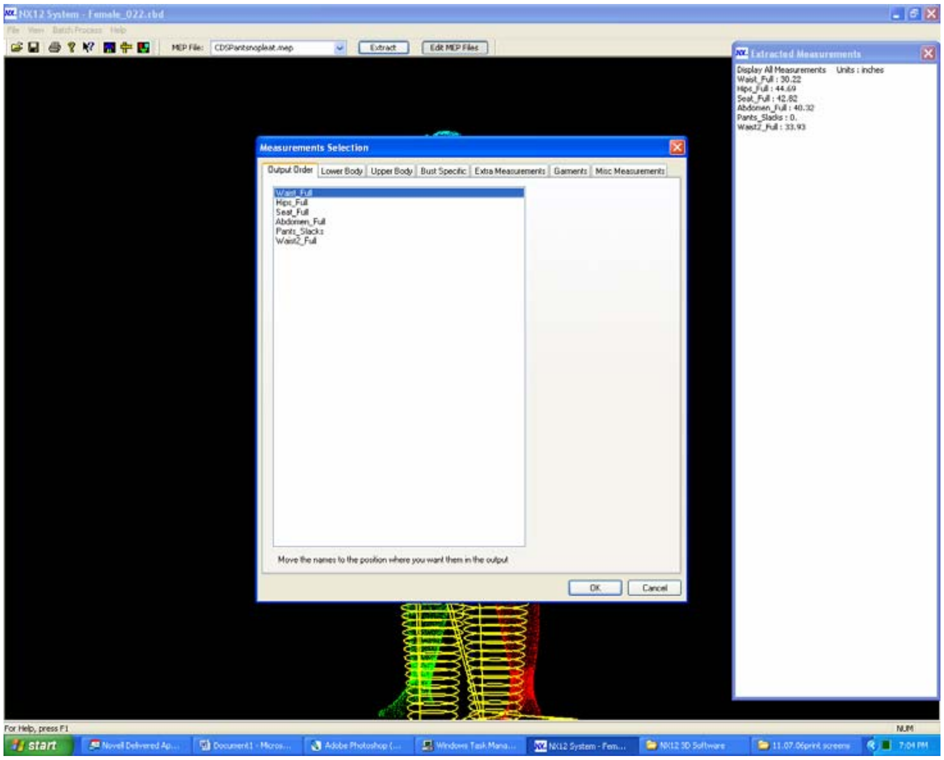
Pant Waistband: Parameter for Pant Waistband



Pant Leg Shaping: Parameter for Pant Leg Shaping



Pant Extractions: Pant Extraction Profile Parameters



APPENDIX B. Participant Post-Fit Evaluation Questionnaire

Post-Fit Evaluation of 3D to 2D
Apparel Products vs. Off-the-Rack Apparel Products

PART I

1. Is finding a garment with "good" fit an issue for you?
_____ Yes
_____ No

If 'YES' please proceed; if 'NO' please skip to question #4

2. Which garments are the hardest for you to find a "good" fit for?
(Mark all that apply)
_____ Shirt (Bodice)
_____ Pants
_____ Skirts
_____ Jackets

3. What areas of your body are the hardest to fit?
(Mark all that apply)
_____ Bust
_____ Waist
_____ Hips
_____ Thighs
_____ Biceps
_____ Sleeve length
_____ Neck
_____ Pant length

PART II

Please indicate your agreement with each of the following statements. (4 – 14)

4. The 3D–2D shirt (bodice) fits better than most off-the-rack bodices I have tried.
Strongly Disagree Neutral Strongly Agree
1 2 3 4 5 6 7 N/A

5. The 3D–2D skirt fits better than most off-the-rack skirts I have tried.
Strongly Disagree Neutral Strongly Agree

1	2	3	4	5	6	7	N/A

6. The 3D–2D pant fits better than most off-the-rack pants I have tried.

Strongly Disagree			Neutral			Strongly Agree	
1	2	3	4	5	6	7	N/A

7. I would pay more for this product because of its ““good”” fit.

Strongly Disagree			Neutral			Strongly Agree
1	2	3	4	5	6	7

PART III

8. Using the body scanner was as comfortable as using a traditional dressing room.

Strongly Disagree			Neutral			Strongly Agree
1	2	3	4	5	6	7

9. Using the body scanner made apparel purchasing more exciting than the traditional retail experience?

Strongly Disagree			Neutral			Strongly Agree
1	2	3	4	5	6	7

10. The fit of the final products makes me more willing to use the body scanner for future apparel purchases.

Strongly Disagree			Neutral			Strongly Agree
1	2	3	4	5	6	7

11. I am likely to use the body scanner for a custom fit apparel product in the future.

Strongly Disagree			Neutral			Strongly Agree
1	2	3	4	5	6	7

12. I am interested in using the body scanner in a retail setting for a custom product?

Strongly Disagree			Neutral			Strongly Agree
1	2	3	4	5	6	7

13. I will/ do recommend using the body scanner to others with fit issues.

Strongly Disagree			Neutral			Strongly Agree
1	2	3	4	5	6	7

14. My interest in finding companies that use this technology to create apparel has increased.

Strongly Disagree			Neutral			Strongly Agree
1	2	3	4	5	6	7

15. Are you interested in having a final garment developed from this process?
_____ Yes
_____ No
_____ I don't know

PART IV

16. Before using the body scanner I was concerned about:

a. Privacy during the process

Strongly Disagree			Neutral			Strongly Agree
1	2	3	4	5	6	7

b. Confidentiality of the image

Strongly Disagree			Neutral			Strongly Agree
1	2	3	4	5	6	7

c. Sanitation of the scanning garments

Strongly Disagree			Neutral			Strongly Agree
1	2	3	4	5	6	7

d. Health concerns about scanners

Strongly Disagree			Neutral			Strongly Agree
1	2	3	4	5	6	7

e. The appearance of the scan image

Strongly Disagree			Neutral			Strongly Agree
1	2	3	4	5	6	7

f. Other ___________________

Strongly Disagree			Neutral			Strongly Agree
1	2	3	4	5	6	7

17. After using the body scanner once, my initial concerns changed?
_____ Yes
_____ No

If 'YES' please proceed; if 'NO' please do not continue

18. In what areas did your initial concerns increase? (Mark all that apply)
_____ Privacy during the process
_____ Confidentiality of the image
_____ Sanitation of the scanning garments
_____ Health concerns about scanners
_____ The appearance of the scan image
_____ Other ___________________

19. In what area did your initial concerns decrease? (Mark all that apply)

_____ Privacy during the process
_____ Confidentiality of the image
_____ Sanitation of the scanning garments
_____ Health concerns about scanners
_____ The appearance of the scan image
_____ Other __________________

Codebook for Questionnaire

Codebook development														
					1	2	3	4	5	6	7	8	9	totals
Column Number	Variable Number	Variable Name	Question Number	Coding Instructions										
1 - 3	1	Respondent ID		001 to 890	4	10	1	2	9	3	5	7	8	
4	2	Record number		1 (same all)	1	1	1	1	1	1	1	1	1	
5 - 6	3	Project Code		1 (same all)	1	1	1	1	1	1	1	1	1	
7 - 8	4	Interview code		as coded										
9 - 14	5	Date code		as coded										
15 - 20	6	Time code		as coded										
21 - 22	7	Validation code		as coded										
23 - 24		BLANK		leave blank										
25	8	Finding "good" fit is a issue	1	1: yes 2: no 9: no response	1	1	1	1	1	2	1	1	2	78%
26	9	shirt hardest to find "good" fit	2a	1: yes 0: no response	1	0	1	0	1	0	0	1	0	4
27	10	pant hardest to find "good" fit	2b	1: yes 0: no response	1	1	1	1	1	0	1	1	0	7
28	11	skirt hardest to find "good" fit	2c	1: yes 0: no response	0	0	0	0	0	0	0	0	0	0
29	12	jackets hardest to find "good" fit	2d	1: yes 0: no response	1	0	0	1	1	0	0	0	0	3
30	13	bust hardest to fit	3a	1: yes 0: no response	1	1	0	0	1	0	1	0	0	4
31	14	waist hardest to fit	3b	1: yes 0: no response	0	0	1	1	0	0	1	1	0	4
32	15	hips hardest to fit	3c	1: yes 0: no response	0	0	0	1	0	0	0	1	0	2
33	16	thighs hardest to fit	3d	1: yes 0: no response	0	0	0	1	0	0	0	1	0	2
34	17	biceps hardest to fit	3e	1: yes 0: no response	0	0	0	0	0	0	0	0	0	0
35	18	sleeve length hardest to fit	3f	1: yes 0: no response	1	0	1	0	1	0	0	0	0	3
36	19	neck hardest to fit	3g	1: yes 0: no response	0	0	0	0	0	0	0	0	0	0
37	20	pant length hardest to fit	3h	1: yes 0: no response	1	1	1	0	1	0	1	1	0	6
38	21	bodice fit	4	1 - 7, Blank: no response, blank: not applicable	6			2	4	3	1	2	1	2.714286

39	22	skirt fit	5	1 - 7, Blank: no response, blank: not applicable	5			5		3	4	3	1	3.5
40	23	pant fit	6	1 - 7, Blank: no response, blank: not applicable	6	5	7			4		6	1	4.833333
41	24	fit satisfaction	7	1 - 7, Blank: no response, blank: not applicable	7	6	6	2	1	4	1	7	1	3.888889
42	25	comfort of using bodyscanner	8	1 - 7, Blank: no response, blank: not applicable	7	7	7	3	7	7	5	5	6	6
43	26	excitement factor of bodyscanner	9	1 - 7, Blank: no response, blank: not applicable	7	4	6	5	5	7	7	7	3	5.666667
44	27	fit satisfaction	10	1 - 7, Blank: no response, blank: not applicable	7	5	7	5	2	5	2	5	1	4.333333
45	28	reuse of bodyscanner	11	1 - 7, Blank: no response, blank: not applicable	7	5	7	4	4	6	5	6	3	5.222222
46	29	retail use of bodyscanner	12	1 - 7, Blank: no response, blank: not applicable	7	5	6	4	2	7	2	5	3	4.555556
47	30	recommendation intentions	13	1 - 7, Blank: no response, blank: not applicable	7	6	7	6	6	6	4	7	4	5.888889
48	31	bodyscanner retailer interest	14	1 - 7, Blank: no response, blank: not applicable	5	5	6	4	7	6	3	7	3	5.111111
49	32	interest in final garment	15	1: yes 2: no 3. I don't know	1	1	1	1	1	1	2	1	3	
50	33	pre privacy concerns	16a	1 - 7, Blank: no response, blank: not applicable	1	5	5	3	1	2	2	5	3	3
51	34	pre confidentiality concerns	16b	1 - 7, Blank: no response, blank: not applicable	2	4	4	3	1	2	2	5	3	2.888889
	35	pre sanitation concerns	16c	1 - 7, Blank: no response, blank: not applicable	1	6	5	2		5	2	5	5	3.875
	36	pre health concerns	16d	1 - 7, Blank: no response, blank: not applicable	1	4	3	2	1	6	2	3	3	2.777778
52	37	pre scan appearance concerns	16e	1 - 7, Blank: no response, blank: not applicable	1	4	6	2	1	3	6	5	4	3.555556
53	38	pre other concerns	16f	1 - 7, Blank: no response, blank: not applicable										

54	39	change in concerns	17	1: yes 2: no 9: no response	2	2	1	2	2	2	2	1	2	22%
55	40	privacy concerns increase	18a	1: yes 0: no response	0	0	0	0	0	0	0	0	0	0
56	41	confidentiality concerns increase	18b	1: yes 0: no response	0	0	0	0	0	0	0	0	0	0
57	42	sanitation concerns increase	18c	1: yes 0: no response	0	0	0	0	0	0	0	0	0	0
58	43	health concerns increase	18d	1: yes 0: no response	0	0	0	0	0	0	0	0	0	0
59	44	scan appearance concerns increase	18e	1: yes 0: no response	0	0	0	0	0	0	0	1	0	1
60	45	other concerns increase	18f	1: yes 0: no response	0	0	0	0	0	0	0	0	0	0
61	46	privacy concerns decrease	19a	1: yes 0: no response	0	0	0	0	0	0	0	1	0	1
62	47	confidentiality concerns decrease	19b	1: yes 0: no response	0	0	1	0	0	0	0	1	0	2
63	48	sanitation concerns decrease	19c	1: yes 0: no response	0	0	1	0	0	0	0	1	0	2
64	49	health concerns decrease	19d	1: yes 0: no response	0	0	0	0	0	0	0	1	0	1
65	50	scan appearance concerns decrease	19e	1: yes 0: no response	0	0	1	0	0	0	0	0	0	1
66	51	other concerns decrease	19f	1: yes 0: no response	0	0	0	0	0	0	0	0	0	0

APPENDIX C. Garment Evaluation Tool

Bodice Garment Evaluation Tool

Bodice Evaluation			
III: Appearance			
Seams			
Fitting Area	**Ideal Fit**	**Item**	**Problem**
Shoulder Seams	Smooth seam across the top of the shoulder starting from side neck and ending at the point where shoulder and arm connect.	Shoulder Seam Position	
		Shoulder Seam Length	
Side Seams	Should be perpendicular to the floor and start from the middle of the armhole to the side of the waist	Bodice Side Seam Uptake	
		Bodice Side Seam Position	
		Bodice Side Seam Angle	
		Bodice Side Seam Length	
Waist Seam Line	The circumference should rest at the natural waist line and should be parallel to the floor.	Bodice Waist Seam Level	
Darts			
Fitting Area	**Ideal Fit**	**Item**	**Problem**
Front Waist Dart	The location of the dart on the waist line is determined by standard calculations along with personal judgment. It should fall where the princess seam would be located which is perpendicular to the waist from the bust point.	Bodice Front Waist Dart Uptake	
		Bodice Front Waist Dart Position (Dart Legs)	
		Bodice Front Waist Dart Angle (apex)	
		Bodice Front Waist Dart Length	
Armhole Dart	Bust darts should end 1" to 1.5" from the bust point for sizes 14- and 2" to 2.5" for sizes 14+.	Armhole Dart Uptake	
		Armhole Dart Position (Dart legs)	
		Armhole Dart Angle (apex)	
		Armhole Dart Length	
Back Waist Dart	It should fall where the princess seam would be located which is perpendicular to the waist from the bust point. Point toward but does not go completely to the fullest part of the area of shaping interest rather it falls slightly shorter.	Bodice Back Waist Dart Uptake	
		Bodice Back Waist Dart Position (dart legs)	
		Bodice Back Waist Dart Angle (apex)	
		Bodice Back Waist Dart Length	
Back Shoulder Darts	Point toward but does not go completely to the fullest part of the area of shaping interest rather it falls slightly shorter, and angled toward center back waist point	Back Shoulder Dart Uptake	
		Back Shoulder Dart Position (dart legs)	
		Back Shoulder Dart Angle (apex)	
		Back Shoulder Dart Length	
Number of Darts		Front Waist Darts	
		Front Armhole Dart	

		Back Waist Darts	
		Back Shoulder Dart	
Neck hole			
Fitting Area	**Ideal Fit**	**Item**	**Problem**
Neckline	Should lay flat around the neckline	Neckline height at Center Front	
		Neckline height at Center Back	
		Neckline Fit Overall (gaping)	
Armhole			
Fitting Area	**Ideal Fit**	**Item**	**Problem**
Armhole	There should not be any gaping at around the arm hole. The armhole should hang level to the front upper chest line at the side seam to not restrict movement	Armhole Fit Overall (Gaping)	
		Armhole Level	
IV: Comfort			
Width Measurement Ease			
Fitting Area	**Ideal Fit**	**Item**	**Problem**
Total Bust Circumference	2", which would be 1/2" pinched out on each side of each side seam at bust location	Bust Ease	
Total Waist Circumference	1", which would be 1/4" pinched out each side of each side seam at waist location. It should also fit close to the body but should not hold in or constrict the body in any way.	Bodice Waist Ease	
Neckline Circumference	"1/8" of ease around the front and back necklines", which would be 1/32" pinched out each side of side seam at neck location.	Neckline Ease	

Taken from Editors of Creative Publishing International, 1987; Handford, 2003; Joseph-Armstrong, 2006; Shepherd, 1997

Skirt Garment Evaluation Tool

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Skirt Evaluation			
III: Appearance			
Seams			
Fitting Area	**Ideal Fit**	**Item**	**Problem**
Side Seams	Should be **perpendicular** to the floor and start from the side of the waist to the hem	Skirt Side Seam Uptake	
		Skirt Side Seam Position	
		Skirt Side Seam Angle	
Darts			
Fitting Area	**Ideal Fit**	**Item**	**Problem**
Front Skirt Darts	Darts closest to the center front should align with the **princess line**. "Should stop **½" to 1" short** of the fullest part of the abdomen."	Front Skirt Dart Uptake	
		Front Skirt Dart Position	
		Front Skirt Dart Angle	
		Front Skirt Dart Length	
Back Skirt Darts	Darts closest to the center front should align with **princess line**. "Should stop **½" to 1" short** of the fullest part of the seat."	Back Skirt Dart Uptake	
		Back Skirt Dart Position	
		Back Skirt Dart Angle	
		Back Skirt Dart Length	
Darts	Should be Max of **2 darts**	Front Waist Darts	
		Back Waist Darts	
IV: Comfort			
Width Measurement Ease			
Fitting Area	**Ideal Fit**	**Item**	**Problem**
Total Waist Circumference	**1"**, which would be 1/4" pinched out each side of each side seam at waist location. It should also fit close to the body but should not hold in or constrict the body in any way.	Skirt Front Waist Ease	
		Skirt Back Waist Ease	
Total Hip Circumference	**3"**, which would be 3/4" pinched out on each side of each side seam at hip location	Skirt Hip Ease	

Taken from Editors of Creative Publishing International, 1987; Handford, 2003; Joseph-Armstrong, 2006; Shepherd, 1997

Pant Garment Evaluation Tool

Pant Evaluation			
III: Appearance			
Seams			
Fitting Area	**Ideal Fit**	**Item**	**Problem**
Leg Side Seams	Should be **perpendicular** to the floor and start from the side of the waist to the hem	Pant Side Seam Uptake	
		Pant side Seam Position	
		Pant side Seam Angle	
Waist Seam Level		Pant waist seam level	
Center Back Seam		Center Back Seam Uptake	
Crotch Seam	" Should follow the contours of the body smoothly" starting from center back waist point between the legs to the center front waist point.	Crotch Seam Rise/ Length	
Darts			
Fitting Area	**Ideal Fit**	**Item**	**Problem**
Front Pant Darts	Darts closest to the center front should align with the **princess line**. "Should stop **½" to 1" short** of the fullest part of the seat."	Center Front Pant Dart Uptake	
		Side Seam Front Pant Dart Uptake	
		Front Pant Dart Position (dart legs)	
		Front Pant Dart Angle (dart apex)	
		Front Pant Dart Length	
Back Pant Darts	Darts closest to the center front should align with the **princess line**. "Should stop **½" to 1" short** of the fullest part of the seat."	Center Back Pant Dart Uptake	
		Side Seam Back Pant Dart Uptake	
		Back Pant Dart Position (dart legs)	
		Back Pant Dart Angle (dart apex)	
		Back Pant Dart Length	
Darts	Should be Max of **2 darts**	Number of Front Darts	
	Should be Max of **2 darts**	Number of Back Darts	
Hems			
Fitting Area	**Ideal Fit**	**Item**	**Problem**
Pant Hem	The full circumference should hang **parallel** to the floor	Pant Hem Seam Level	
IV: Comfort			
Width Measurement Ease			
Fitting Area	**Ideal Fit**	**Item**	**Problem**
Total Waist Circumference	**1"**, which would be 1/4" pinched out each side of each side seam at waist location. It should also fit close to the body but should not hold in or constrict the body in any way.	Pant Waist Ease	
Total Hip Circumference	**3"**, which would be 3/4" pinched out on each side of each side seam at hip location	Pant Hip Ease	

Taken from Editors of Creative Publishing International, 1987; Handford, 2003; Joseph-Armstrong, 2006; Shepherd, 1997

APPENDIX D. Classification of Participant Groups

The Department of Health and Human Services (HHS) and the Department of Agriculture (USDA) Body Mass Index Table

BMI	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Height	Weight in Pounds																
4'10"	91	96	100	105	110	115	119	124	129	134	138	143	148	153	158	162	167
4'11"	94	99	104	109	114	119	124	128	133	138	143	148	153	158	163	168	173
5'	97	102	107	112	118	123	128	133	138	143	148	153	158	163	158	174	179
5'1"	100	106	111	116	122	127	132	137	143	148	153	158	164	169	174	180	185
5'2"	104	109	115	120	126	131	136	142	147	153	158	164	169	175	180	186	191
5'3"	107	113	118	124	130	135	141	146	152	158	163	169	175	180	186	191	197
5'4"	110	116	122	128	134	140	145	151	157	163	169	174	180	186	192	197	204
5'5"	114	120	126	132	138	144	150	156	162	168	174	180	186	192	198	204	210
5'6"	118	124	130	136	142	148	155	161	167	173	179	186	192	198	204	210	216
5'7"	121	127	134	140	146	153	159	166	172	178	185	191	198	204	211	217	223
5'8"	125	131	138	144	151	158	164	171	177	184	190	197	203	210	216	223	230
5'9"	128	135	142	149	155	162	169	176	182	189	196	203	209	216	223	230	236
5'10"	132	139	146	153	160	167	174	181	188	195	202	209	216	222	229	236	243
5'11"	136	143	150	157	165	172	179	186	193	200	208	215	222	229	236	243	250
6'	140	147	154	162	169	177	184	191	199	206	213	221	228	235	242	250	258
6'1"	144	151	159	166	174	182	189	197	204	212	219	227	235	242	250	257	265
6'2'	148	155	163	171	179	186	194	202	210	218	225	233	241	249	256	264	272
6'3'	152	160	168	176	184	192	200	208	216	224	232	240	248	256	264	272	279
	Healthy Weight						Overweight					Obese					

Taken from the Department of Health and Human Services (HHS) and the Department of Agriculture (USDA) Body Mass Index Table

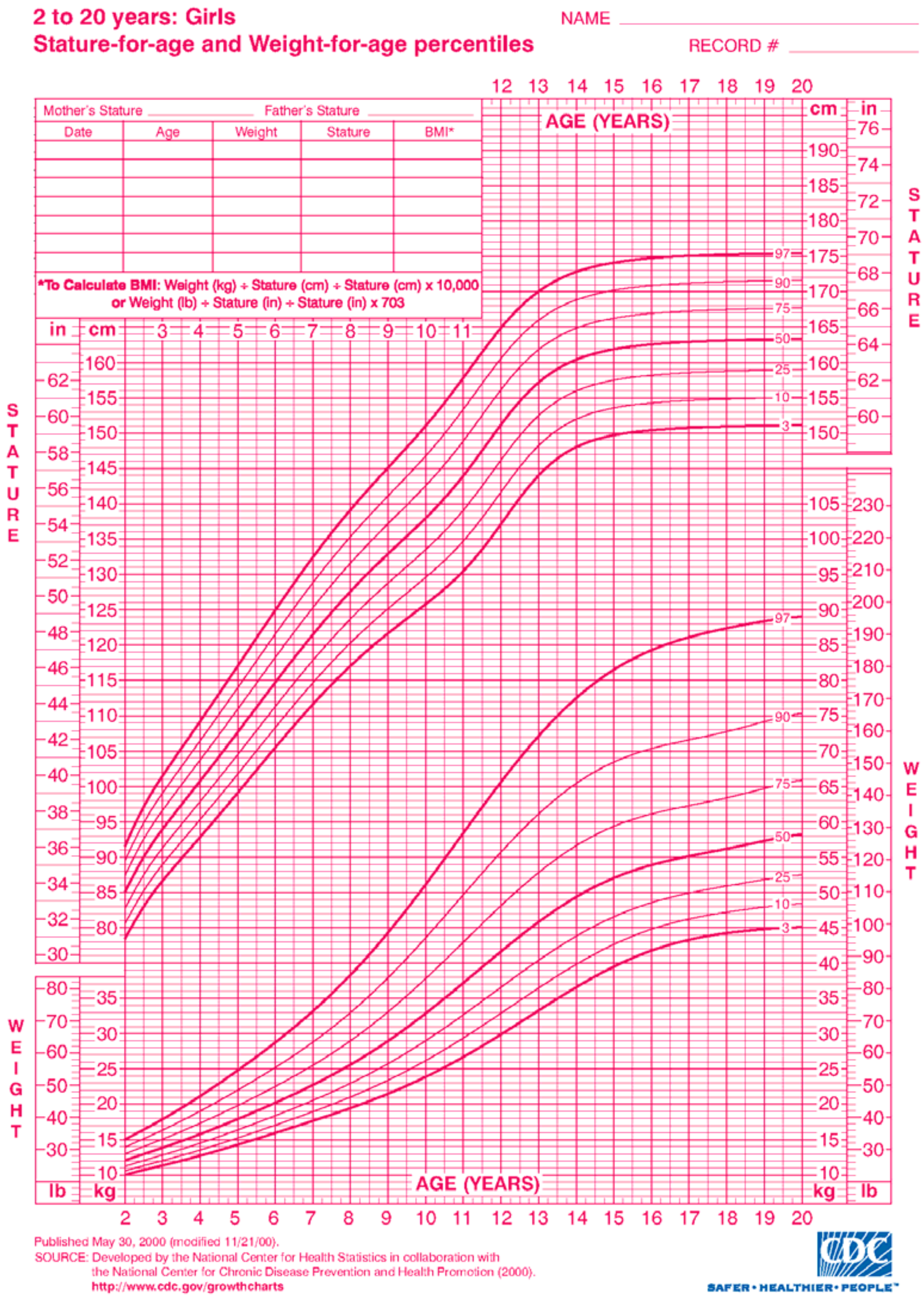
Missy ASTM-5585 Sizing Standards used to determine participant circumferential and length classifications

MISSY SIZING--ASTM 5585

Measurement	2	4	6	8	10	12	14	16	18	20
GIRTH:										
Bust	32.00	33.00	34.00	35.00	36.00	37.50	39.00	40.50	42.50	44.50
Waist	24.00	25.00	26.00	27.00	28.00	29.50	31.00	32.50	34.50	36.50
High hip	31.50	32.50	33.50	34.50	35.50	37.00	38.50	40.00	42.00	44.00
Hip	34.50	35.50	36.50	37.50	38.50	40.00	41.50	43.00	45.00	47.00
Neck Base	13.50	13.75	14.00	14.25	14.50	14.88	15.25	15.63	16.13	16.63
Upper arm	10.00	10.25	10.50	10.75	11.00	11.38	11.75	12.13	12.75	13.38
Thigh, Max	19.50	20.25	21.00	21.75	22.50	23.50	24.50	25.50	26.75	28.00
Total Crotch	25.00	25.75	26.50	27.25	28.00	28.75	29.50	30.25	31.00	31.75
VERTICAL										
Cervical height	54.50	55.00	55.50	56.00	56.50	57.00	57.50	58.00	58.50	59.00
Waist height	39.25	39.50	39.75	40.00	40.25	40.50	40.75	41.00	41.25	41.50
Hip height	31.25	31.50	31.75	32.00	32.25	32.50	32.75	33.00	33.25	33.50
Crotch height	29.50	29.50	29.50	29.50	29.50	29.50	29.50	29.50	29.50	29.50
Ft waist length	13.50	13.75	14.00	14.25	14.50	14.75	15.00	15.25	15.50	15.75
Bk waist length (necktowaist)	15.50	15.75	16.00	16.25	16.50	16.75	17.00	17.25	17.50	17.75
Rise	9.75	10.00	10.25	10.50	10.75	11.00	11.25	11.50	11.75	12.00
WIDTH & LENGTH										
Across Schoulder	14.38	14.63	14.88	15.13	15.38	15.75	16.13	16.50	17.00	17.50
Cross-back width	13.88	14.13	14.38	14.63	14.88	15.25	15.63	16.00	16.50	17.00
Cross-chest width	12.88	13.13	13.38	13.63	13.88	14.25	14.63	15.00	15.50	16.00
Shoulder length	4.94	5.00	5.06	5.13	5.19	5.31	5.44	5.56	5.75	5.93
Shoulder slope (degrees)	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00
Arm length (shlder to wrist)	22.94	23.13	23.31	23.50	23.69	23.88	24.06	24.25	24.44	24.63
Bust point to bust point	7.00	7.25	7.50	7.75	8.00	8.25	8.50	8.75	9.00	9.25

taken from Simmons, K. P. (2002). <u>Body shape analysis using three-dimensional body scanning technology.</u>

The National Center for Health Statistics and National Center for Chronic Disease Prevention and Health Promotion (May 2000) height and weight percentiles for women.



Taken from the National Center for Health Statistics and National Center for Chronic Disease Prevention and Health Promotion (May 2000) height and weight percentiles for women.

APPENDIX E. Garment Numeric Corrections

Bodice Frequency Corrections

Bodice Shoulder Seams		1	2	3	4	5	7	8	9	Sum	%
Item	**Problem**										
Bodice Shoulder Seam Position	Slanting to front of body at neck point	x			x			x		3	38%
	Slanting to the back of body at armhole	x						x		2	25%
Bodice Shoulder Seam Length	too short at back armhole			x				x	x	3	38%
	too short in front armhole			x					x	2	25%
	too long at back armhole	x								1	13%
	too long at front armhole	x						x		2	25%
	too long at back neck	x	x	x	x	x	x	x	x	8	100%
	too long at front neck	x	x	x	x	x	x		x	7	88%

Bodice Neckline		1	2	3	4	5	7	8	9	Sum	%
Item	**Problem**										
Bodice Neckline Height at Center Front	too high		x	x	x	x	x		x	6	75%
Bodice Neckline Height at Center Back	too high	x	x		x	x	x	x	x	7	88%
Bodice Neckline Fit Overall (gaping)	gaping at shoulder seam		x							1	13%

Bodice Side Seams		1	2	3	4	5	7	8	9	Sum	%
Item	**Problem**										
Bodice Side Seam Uptake	too loose at armhole	x					x			2	25%
Bodice Side Seam Position	Too far from center front	x		x	x			x	x	5	63%
Bodice Side Seam Angle	angle slanted away from center front at waist		x						x	2	25%
Bodice Side Seam Length	too short at waist	x								1	13%

Bodice Bust Darts		1	2	3	4	5	7	8	9	Sum	%
Item	**Problem**										
Bodice Front Waist Dart Uptake	too much uptake	x	x							2	25%
Bodice Front Waist Dart Position (dart legs)	too close to center front	x	x		x	x	x			5	63%
Bodice Front Waist Dart Angle (apex)	too close to center front	x				x				2	25%
Bodice Front Waist Dart Length	too long at apex	x	x	x	x	x	x	x	x	8	100%
Bodice Armhole Dart Uptake	too little uptake		x							1	13%
	too much uptake	x							x	2	25%
Bodice Armhole Dart Position (dart legs)	dart leg too high	x							x	2	25%
Bodice Armhole Dart Length	too long at apex	x	x	x	x	x	x	x	x	8	100%

Bodice Back Darts		1	2	3	4	5	7	8	9	Sum	%
Item	**Problem**										
Bodice Back Waist Dart Uptake	need dart			x			x	x		3	38%
Bodice Back Waist Dart Position (dart legs)	too close to center back				x	x				2	25%
Bodice Back Waist Dart Length	too long at apex				x	x				2	25%
Back Bodice Shoulder Dart Length	too long at apex	x			x	x				3	38%

Bodice Armhole		1	2	3	4	5	7	8	9	Sum	%
Item	**Problem**										
Bodice Armhole Fit Overall (Gaping)	to loose in back armhole				x				x	2	25%
Bodice Armhole Level	too short at chest level back armhole	x								1	13%
	too long chest level at front armhole			x	x		x	x		4	50%
	too low at side seam	x								1	13%
	too high at Side Seam		x	x			x	x		4	50%

Skirt Frequency Corrections

Skirt Side Seams		1	2	3	4	5	7	8	Sum	%
Item	**Problem**									
Skirt Side Seam Position	too far from center front				x				1	14%

Skirt Darts		1	2	3	4	5	7	8	Sum	%
Item	**Problem**									
Front Skirt Dart Uptake	needs dart	x			x	x	x		4	57%
	too little uptake		x	x				x	3	43%
Front Skirt Dart Position (dart legs)	too close to center front			x				x	2	29%
Front Skirt Dart Angle (dart apex)	too close to center front			x				x	2	29%
Front Skirt Dart Length	too short at apex		x	x					2	29%
Back Skirt Dart Uptake	too little uptake						x		1	14%
Back Skirt Dart Position (dart legs)	too far from center back		x		x	x	x	x	5	71%
Back Skirt Dart Angle (dart apex)	too far from center back		x		x	x	x	x	5	71%
Back Skirt Dart Length	too long at apex		x	x	x	x	x	x	6	86%

Skirt Ease		1	2	3	4	5	7	8	Sum	%
Item	**Problem**									
Skirt Front Waist Ease	too much ease	x	x	x	x	x	x	x	7	100%
Skirt Back Waist Ease	too much ease						x		1	14%

Pant Frequency Corrections

Pant Seams		1	3	4	6	7	8	10	Sum	%
Item	**Problem**									
Pant Side Seam Uptake	too little uptake			x					1	14%
	too much uptake					x			1	14%
Pant Side Seam Position	Too close to center back			x					1	14%
Pant Side Seam Angle	too far from center front at waist		x		x				2	29%
Pant Waist Seam Level	too high at center back and center front						x		1	14%
	too high at center ft	x							1	14%
Center Back Seam Uptake	too little uptake	x							1	14%
Crotch Seam Rise/ Length	too long	x				x		x	3	43%

Pant Darts		1	3	4	6	7	8	10	Sum	percent
Item	**Problem**									
Front Pant Dart Uptake	needs additional dart							x	1	14%
	too little uptake						x		1	14%
Front Pant Dart Position (dart legs)	too far from center front		x	x		x	x		4	57%
Front Pant Dart Angle (dart apex)	too far from center front		x	x		x	x		4	57%
Front Pant Dart Length	too long at apex		x					x	2	29%
Back Pant Dart Uptake	too little uptake						x		1	14%
Back Pant Dart Position (dart legs)	too far from center back					x			1	14%
Back Pant Dart Angle (dart apex)	too far from center back					x			1	14%
Back Pant Dart Length	too long at apex	x	x		x	x	x	x	6	86%
Number of Pant Front Darts	needs dart							x	1	14%
Number of Pant Back Darts	too many				x			x	2	29%

Pant Hem		1	3	4	6	7	8	10	Sum	percent
Item	**Problem**									
Pant Hem Seam Level	too long	x	x	x	x	x	x	x	7	100%

Pant Width Measurement Ease		1	3	4	6	7	8	10	sum	percent
Item	**Problem**									
Pant Waist Ease	too little ease			x		x			2	29%
	too much ease	x					x	x	3	43%

Bodice Numeric Corrections

	Bodice Seams												
	Shoulder Seams								Bodice Side Seams				Bodice Waist Seam
	Bodice Shoulder Seam Position				Bodice Shoulder Seam Length				Bodice Side Seam Uptake	Bodice Side Seam Position	Bodice Side Seam Angle	Bodice Side Seam Length	Bodice Waist Seam Level
	Back Neck Point	Back Armhole Point	Front Neck Point	Front Armhole Point	Back Neck Point	Back Armhole Point	Front Neck Point	Front Armhole Point	change uptake at armhole by:	Move seam toward CENTER FRONT	move SS waist point toward Center front	change side seam waist line seam level by:	change Center front seam level by:
2					-1.00		-1.00				1.00		
1	-1.38	0.75	-0.38	0.75	-1.00	-0.50	-1.00	-0.50	-0.25	2.00		0.50	0.50
3					-1.00	1.00	-1.00	1.00		0.75			
4	-1.00		1.00		-0.63		-0.63			1.25			
5					-0.50		-0.50						
7					-0.38		-0.38		-0.50				
8	-0.25	0.50	0.75	-0.25	-1.00	0.50		-1.00		2.00			
9					-0.25	1.00	-0.25	1.25		1.75	1.13		
Sum	-0.88	0.63	0.46	0.25	-0.72	0.50	-0.68	0.19	-0.38	1.55	1.06	0.50	0.50

	Bodice Darts																			
	Front Waist Dart				Armhole Dart				Back Waist Dart				Back Shoulder Dart				Number of Darts			
	Bodice Front Waist Dart Uptake	Bodice Front Waist Dart Position (dart legs)	Bodice Front Waist Dart Angle (apex)	Bodice Front Waist Dart Length	Bodice Armhole Dart Uptake	Bodice Armhole Dart Position (Dart legs)	Bodice Armhole Dart Angle (apex)	Bodice Armhole Dart Length (apex)	Bodice Back Waist Dart Uptake	Bodice Back Waist Dart Position (dart legs)	Bodice Back Waist Dart Angle (apex)	Bodice Back Waist Dart Length	Bodice Back Shoulder Dart Uptake	Bodice Back Shoulder Dart Position (dart legs)	Bodice Back Shoulder Dart Angle (apex)	Bodice Back Shoulder Dart Length	Bodice Front Waist Darts	Bodice Front Armhole Dart	Bodice Back Waist Darts	Bodice Back Shoulder Dart
	change uptake by:	move toward side seam by:	move toward side seam by:	Change apex by:	Change uptake by:	change leg positions by:		apex	additional uptake for each dart	move toward side seam by:		apex				apex			additional darts needed	
2	-1.00	1.00		-1.25	0.77			-1.25												
1	-1.50	0.75	0.75	-1.25	-0.25	-2.75		-2.25								-2.50				
3				-1.75				-1.00	0.75										1.00	
4		0.75		-1.50				-1.25		0.15		-1.00				-1.00				
5		0.50	0.50	-1.00				-1.00		1.00		-1.50				-1.50				
7		1.00		-2.00				-0.63	1.00										1.00	
8				-3.25				-0.50	0.50										1.00	
9				-1.00	-0.75	-0.75		-1.13												
sum	-1.25	0.80	0.63	-1.63	-0.08	-1.75	0.00	-1.13	0.75	0.57	0.00	-1.25	0.00	0.00	0.00	-1.67	0.00	0.00	1.00	0.00

	Bodice Neck hole			**Bodice Armhole**				**Bodice Ease**		
	Neckline			Armhole				Total Bust Circumference	Total Waist Circumference	Neckline Circumference
	Bodice Neckline Height at Center Front	Bodice Neckline Height at Center Back	Bodice Neckline Fit Overall (gaping)	Bodice Armhole Fit Overall (Gaping)	Bodice Armhole Level			Bodice Bust Ease	Bodice Waist Ease	Bodice Neckline Ease
			change shoulder seam height by:	back gaping: remove from armhole seam	at chest level of armhole front	at chest level of armhole back	at side seam	change circumference by:	change circumference by:	change circumference by:
2	-1.50	-1.50	-0.25				-1.00	1.00	5.00	-0.50
1		-0.63				0.50	0.50		3.00	
3	-1.25				-1.00		-0.75		-1.50	
4	-1.00	-0.50		-0.25	-0.50					-0.50
5	-0.50	-0.50								
7	-1.00	-0.63			-1.00		-0.25	-2.00	-2.00	
8		-1.00			-1.00		-0.88	-1.00	0.50	
9	-0.25	-0.75		-0.63						
Sum	-0.92	-0.79	-0.25	-0.44	-0.88	0.50	-0.48	-0.67	1.00	-0.50

Skirt Numeric Corrections

Group	Subgroup	Item	Action	1	2	3	4	5	7	8	Sum
Skirt Seams	Skirt Side Seams	Skirt Side Seam Uptake	change uptake by:								0.000
		Skirt Side Seam Position	Move seam toward center front				0.250				0.250
		Skirt Side Seam Angle	move SS waist point toward Center front								0.000
Skirt Darts	Front Waist Dart	Skirt Front Waist Dart Uptake	additional uptake for each dart	0.750	0.500	1.000	0.375	0.500	0.500	1.000	0.661
		Skirt Front Waist Dart Position (dart legs)	move toward side seam by:			-0.430				-0.500	-0.465
		Skirt Front Waist Dart Angle (apex)	move toward side seam by:			-0.430				-0.500	-0.465
		Skirt Front Waist Dart Length	Change apex by:		1.250	3.625					2.438
	Back Waist Dart	Skirt Back Waist Dart Uptake	additional uptake for each dart						0.500		0.500
		Skirt Back Waist Dart Position (dart legs)	move toward center back by:		2.000		0.897	0.250	1.000	1.000	1.029
		Skirt Back Waist Dart Angle (apex)	move toward center back by:		2.000		0.897	0.250	1.000	1.000	1.029
		Skirt Back Waist Dart Length	Change apex by:		-1.250	-1.000	-2.250	-1.250	-3.500	-2.500	-1.958
	Number of Darts	Skirt Front Waist Darts	additional darts needed	1.000			1.000	1.000	1.000		1.000
		Skirt Back Waist Darts	additional darts needed								0.000
Skirt Ease	Total Waist Circumference	Skirt Waist Ease	change circumference by:	-1.500	-1.000	-2.000	-0.750	-1.000	-2.000	-2.000	-1.464
	Total Hip Circumference	Skirt Hip Ease	change circumference by:								0.000

Pant Numeric Corrections

				1	3	4	6	7	8	10	
Pant Seams	Leg Side Seams	Pant Side Seam Uptake	change uptake by:			-0.58		0.25			-0.17
		Pant Side Seam Position	Move seam toward center front			-0.14					-0.14
		Pant Side Seam Angle	move SS waist point toward Center front		0.50		2.00				1.25
	Waist Seam Level	Pant waist seam level	Center front waist seam	-0.63					-0.25		-0.44
			Center back waist seam						-0.50		-0.50
	Center Back Seam	Pant Center Back Seam Uptake	change uptake by:	-0.75							-0.75
	Crotch Seam	Pant Crotch Seam Rise/ Length	change length by:	-3.25				-2.00		-3.75	-3.00
Pant Darts	Front Waist Dart	Pant Center Front Waist Dart Uptake	additional for 1 dart						0.50	1.00	0.75
		Pant Front Waist Dart Position (dart legs)	move toward center front by:		1.50	0.53		0.76	1.00		0.95
		Pant Front Waist Dart Angle (apex)	move toward center front by:		1.50	0.53		0.76	1.00		0.95
		Pant Front Waist Dart Length	Change apex by:		-0.50					-0.75	-0.63
	Back Waist Dart	Pant Center Back Waist Dart Uptake	additional uptake for each dart						0.25		0.25
		Pant Back Waist Dart Position (dart legs)	move toward center back by:					0.50			0.50
		Pant Back Waist Dart Angle (apex)	move toward center back by:					0.50			0.50
		Pant Back Waist Dart Length	Change apex by:	-2.25	-0.75		-1.50	-1.25	-2.00	-2.50	-1.71
	Number of Darts	Pant Front Waist Darts								1.00	1.00
		Pant Back Waist Darts	additional darts needed				-1.00			-1.00	-1.00

	Pant Hem	Pant Ease	
	Pant Hem	Total Waist Circumference	Total Hip Circumference
	Pant Hem Seam Level	Pant Waist Ease	Pant Hip Ease
	change hem height by:	change circumference by:	change circumference by:
1	-2.00	-0.75	
3	-1.50		
4	-1.00	-0.58	
6	-1.50		
7	-1.75	-1.00	
8	-2.25	-1.00	
10	-1.75	1.00	
	-1.68	-0.47	0.00