ABSTRACT

HWANG, SU-JEONG. Standardization and Integration of Body Scan Data for Use in the Apparel Industry – Body Scan Data Connectivity with Apparel CAD-. (Under the direction of Cynthia L. Istop and Trevor J. Little.)

The purpose of this research was to provide a methodology for standardization and connectivity of body measurement data for apparel applications between body scanning systems and CAD systems to support further research of system integration in the apparel industry. This research has led to the development of standardization of the body measurement terminology and a data file format to connect the apparel CAD and 3D body scanning systems for the exchange of body measurement data for use in pattern design or alteration.

A Metaphor Matching Process (MMP) was designed for developing a set of Identification Codes with syntax to match and identify body measurements. And, an exchangeable body measurement data in XML (eXtensible Markup Language) format, called MMP XML, was developed for achieving standardization of the body measurement terminology for bi-directional interpretation and transmission of data generated by 3D body scanning systems and 2D CAD pattern generation systems. Then, validation was accomplished by format data exchange testing with Gerber Technology, Inc. and [TC]².

XML format data was gathered from an apparel CAD system and a body scan system. The XML format data was converted into a database system to demonstrate the connectivity between apparel pattern data and body scan data for standardization and integration. A logical IDEF1X model of data flow structure was developed for the body scan data connectivity with apparel CAD.
STANDARDIZATION AND INTEGRATION OF BODY SCAN DATA
FOR USE IN THE APPAREL INDUSTRY
- Body Scan Data Connectivity with Apparel CAD -

by

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APPROVED BY:

[Signatures]
Chair of Advisory Committee
Co-chair of Advisory Committee
DEDICATION

To my mother and late father

who devoted themselves to the support of me

in this journey of my life.
BIOGRAPHY

The author, Su-Jeong Hwang, the first daughter of late Haksoo Hwang who was an engineer and business man and Yeongchi Kim, was born on February 10, 1970 in Seoul, Korea. She has one brother, Sung-Jeong Hwang who is a sculptor.

Her training of design clothing was done in Sungshin Women’s University in Seoul, Korea. She studied many aspects of clothing and textiles, including marketing, design, history, and the social psychology of clothing. She received a Bachelor degree in Textiles & Clothing Design in February 1992, and a Master degree in Clothing in February 1994. During undergraduate school, she was awarded several merit scholarships for academic achievement.

In 1989, she had her first exhibition of fashion illustration at GumKang Gallery and second at Grand Department Store Gallery in Seoul, Korea. In 1991, she was selected and served a year as a fashion show coordinator for the 2nd annual alumni fashion show in the department of Textiles and Clothing Design. While she was in the graduate school, she was awarded a research assistantship and served as a teaching assistant for apparel design and marketing. Her performance in school was a result of a deep affinity for and commitment to the subject. In summer 1993, she took apparel design courses from the Fashion Institute of Technology (F.I.T.) in New York to prepare her master thesis about history of fashion illustration.

Upon the completion of her master degree, she decided to study Textile Development & Marketing at the F.I.T. in New York. In December 1997, she graduated from F.I.T. as cum laude and received an Associate Applied Science degree. She learned
practical concepts of the textile field such as textile converting & costing, textile finishing, dyeing and marketing. While at F.I.T. in Manhattan in New York, she had better view of the major fashion market in the Unite State and it was a great opportunity to study on textiles and apparel marketing. Studying at F.I.T. further peaked her interest in the field and in the industry within the United State.

In 1998, as she realized the need of computer knowledge in the apparel industry, she entered A.A.S. degree program for computer programming in the Department of Management Information System (MIS) in Northeastern University in Boston. It was there that she was inspired for creating management systems for apparel applications.

In 1999, she entered into Ph.D. program at Department of Textiles and Apparel Technology in the College of Textiles in North Carolina State University, and worked for a National Textile Center (NTC) project as a research assistant. During her Ph.D. program, she had conferences and published papers with encouragement by her advisor, Dr. Cynthia Istook who gave her most influence. In 2000, she became a sub committee member of ASTM to make standards for apparel applications. In 2002, she was married to Joseph Michael Shin who is a second son of the late Dr. Sungill Shin and Keeyong Shin. She has a son, Brandon Shin who brought her the most happiness in her life. Through her experiences, she has a deep and broad knowledge of textile and apparel technology and management.
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CHAPTER I

INTRODUCTION

In the apparel industry, the ability to customize garments for fit is directly tied to the availability of a comprehensive and accurate set of body measurements for each consumer. A first step in determining correct sizing or creating customized garments is obtaining accurate measurements of specified parts of the human body. Historically, tailors, fashion designers and apparel pattern makers have used traditional tape measuring methods to obtain the physical body measurements.

The traditional tape measuring method used in the apparel industry is time consuming, invasive, and often inconsistent. Measurements vary according to the person taking the measurements. To obtain accurate physical measurements, a basic knowledge of anthropometry and set of skills are required that are not often found in the average retail salesperson. For example, a 1988 anthropometric survey of US Army personnel required 4 hours to physically landmark, measure, and record the data of one subject (Paquette, 1996).

Until recently, only tailors and couture houses still used real body measurements to create or alter the clothing they produced. Historically, the U.S. ready-to-wear apparel industry started with clothing for men in the early 1800s, almost half a century before women’s ready-to-wear had its beginnings. As industrialization developed in the early nineteenth century, a new mass market began to emerge (Jarnow & Guerreiro, 1991). One of the biggest boosts to the men’s ready-to-wear clothing industry came from the government orders for soldiers’ uniforms during the Civil War. In order to facilitate the
production of its uniforms, the Army surveyed the height and chest measurements of more than a million recruits, and thus provided the first mass of statistical data on the form and build of American men. After the war, the results of the Army study were made available to producers of men’s civilian clothing (Jarnow & Guerreiro, 1991).

The manufacture of ready-to-wear is based on standardized sizes in sufficient variety so that almost any figure can be accommodated by one of them. In the early years of the industry, each manufacturer worked out its own set of sizes and made garments to its own specifications, hoping to fit as many people as possible. The fit of these early garments was far from perfect (Jarnow & Guerreiro, 1991). The mass production strategies encouraged the move from garments made to fit to garments made to size with sizing systems that have developed through the years. However, the sizing systems are still neither standardized nor related to the average human’s body measurements.

Most people have a problem with fit in the clothing that is currently available in the marketplace. There is a very large sector of the population dissatisfied with garment fit today. According to Kurt Salmon Associates Consumer Outlook, 57% of US shoppers stated fit problems with standard sizes (IntelliFit Corp., 2003), and as a result, 40% of the purchased clothing is returned (Telmat industire, 2002). This underlying dissatisfaction provided impetus for mass customization in the apparel industry.

The development of three-dimensional body scanning technology may have significant potential for use in the apparel industry for a number of reasons. First, this technology has the potential for obtaining an unlimited number of measurements of human bodies in a matter of seconds. Because an image of the body is captured during
the scanning process, the location and description of the measurements can be rapidly altered as needed. Second, the measurements extracted from body scanning systems have the potential of being more precise and reproducible than measurements obtained through the physical measurement process. Third, with the availability of an infinite number of measurements, the possibility exists for garments to be created to fit to the three-dimensional shapes of human bodies. Finally, the scanning technology allows measurements to be obtained in a digital format that might be connected automatically into apparel CAD systems. This reduces errors, and eliminates the human involvement that takes additional time. Ultimately, the body scanning technology will enable apparel manufacturers to design mass customized garments.

The current available body scanning systems for apparel applications were developed by the following companies world wide: Textile Clothing Technology Corporation ([TC]²), Cyberware, Inc., Telmat Industrie, Tecmath AG, Wicks & Wilson Ltd., and Hamamatsu Photonics. In 1998, the Civilian American and European Surface Anthropometry Resource program (CAESAR) at Wright-Patterson Air Force Base initiated the largest scale anthropometric survey performed in over 30 years (Brunsman et al., 1997; CAESAR, 1999; Workman & Lentz, 2000). It was the first international survey of its kind to utilize body scan technology (CAESAR, 1999). The approach was to start in the United States, the NATO member Nation with the largest population, followed by the Netherlands, whose population contains the tallest people on average in NATO, and Italy whose population contains some of the shortest people on average in
NATO (Brunsman et al., 1997). The Cyberware WB4 whole body scanner was used in this study (Potts, 1997; Caesar, 1999).

The body scan technology is already being used in the apparel industry. In August 1999, Levi’s first installed a 3D body scanner for measuring the customers’ body size digitally in San Francisco (Yu, 1999). Marks and Spencer tried custom-fit suits in London in 1996 (Yu, 1999). Brooks Brothers offers digital tailoring with a process of using a scanner to take body measurements that are translated into a computer program for fast customization of men’s suits (Cohen, 2002).

Ideally, a customer’s body is scanned within a few seconds in a retail store. Then the body measurement data is sent to a factory to produce the garments in a few days. Integrating measurement data from the 3D body scanning system into commercially available CAD/CAM software can significantly reduce inventory levels of garments and cut order lead-time for customized garments, increasing efficiency of the workflow process within an apparel manufacturing process. In addition, the body scan technology may support the development of 3D virtual shopping. Virtual displays via the web may enhance Business-to-Consumer (B2C) applications since consumers could purchase according to more accurate garment evaluation with the virtual garment displays. It may be a natural progression for a sector of manufactured apparel to move from mass production to mass customization with these technologies. An integrated set of technologies with standardization of data is necessary for mass customization, leading to a shortened time for product design and development of customized garments.
Each body scanning system has its own methods of data acquisition, measurement extraction, and output of measurement results. Some body scanning systems have measurement extraction software to display a set of selected body measurements from their raw data. An industry approved standard data file format does not exist for the transmission of body scan data that all recipients can extract the critical measurements as needed for designing the product. Furthermore, the scan data cannot be compared between systems because of the lack of an approved standard format and the following limitations.

First, a current limitation of standardization between body scan data and apparel CAD/CAM system is the inability to integrate body scan data automatically with existing apparel systems. Body measurement data is acquired by extraction software within the specific body scanning system used, and the data is manually entered into specific size code tables previously created in the CAD software. Then, the CAD user must manually create the patterns and a marker order based on the body scan data as entered into the size code table. If necessary, an alteration program adjusts the pattern. This procedure is an extremely complicated and time-consuming process.

Second, there are no approved standard file formats and standard of the semantics with syntax for transmission of body measurements between body scanning companies and CAD companies. In addition, there is no standard set of critical body measurements for CAD generation of a pattern. These absences of approved standards might cause critical body measurements required by an apparel company to be different from the measurements offered by a body scan company.
Third, each body scanning system has its own methods of data acquisition, extraction, and output. Some of these systems have measurement extraction software to interpret their data, and different file formats are used for the interpretation of the final body measurements. An approved standard file format of syntax and semantics does not yet exist for the transmission of body scan data. These limitations restrict many of the potential advantages that can be realized by integrating body scanning systems and apparel CAD.

The following function could be used to describe providing a garment with good fit: \( Y = f(X) \). When \( Y \) is the output of a perfect fitting garment, the following inputs and variables are considered: \( X_1 = \) ‘Body measurement data’; \( X_2 = \) ‘Body scanning systems’; \( X_3 = \) ‘CAD systems’. This means that perfect fitting garments are not only based on body measurement data. Even though body measurement data is one of the variables influencing the fit, interpretation of the body measurements is very important because the interpretation impacts other variables.

Therefore, a set of standards is required for integrating the processes of 3D body scanning and CAD systems. In addition, creating a set of standards for body measurement terminology and methodology along with the integration process is very important for customization in the apparel industry since it will assist in the fit of the final garment. The purpose of this research is to provide a methodology for standardization and connectivity of body measurement data for apparel applications between body scanning systems and CAD systems to support further research of system integration in the apparel industry.
CHAPTER II

REVIEW OF RELATED LITERATURE

In this Chapter, related literature is presented in the following categories:
advanced apparel technologies for mass customization, new 3D body measurement
technologies for apparel production, body measurement standards and body scan data file
formats.

Advancing Apparel Technologies for Mass Customization

Mass customization is the mass production of individually customized goods and
services (Pine, 1993). Mass customization is rooted in the ethos of customer service, and
it is a direct response to the feeling of alienation felt by customers who respond to their
anonymous status by behaving in a commercially promiscuous manner (Kelly, 1997).
According to Kelly (1997), mass customization is assisting the customer to select the
optimum product for his or her needs, and then providing adjusted products as the needs
of the customer change.

Apparel CAD suppliers have responded to the needs of mass customization by
providing tools for customized garments. Apparel CAD suppliers interpreted the
meaning of mass customization to be the manufacture of articles in an individualized
manner, devised, designed and manufactured for client specific types of demand
(Investronica Sistemas, 2003). Increasingly, consumers are demanding greater
customization and personalization (Wright, 2000), and the solutions of mass
customization have been a focus for the apparel industry.
Until now, apparel manufacturers have been focused on mass production using their in-house sizing systems. However, alterations are still necessary because the sizing system is not applicable for all individual customers. As a result, there is an increase in the number of dissatisfied consumers who return their clothing purchases.

According to Kurt Salmon Associates Consumer Outlook, 62% of US shoppers cannot find clothes that fit, 59% claimed inconsistent fit within one brand, and 57% stated fit problems with standard sizes (Intellifit Corp., 2003). As a result, 40% of the purchased clothing is returned and 28% of consumers are reluctant to order from catalogs because they're concerned about getting the right size (Telmat Industrie, 2002). This increase has encouraged apparel manufacturers and retailers to gain customer loyalty by allowing the buyer to customize garments by choosing the size, color and style from a predetermined list of choices.

In the current situation, mass customization seems an ideal concept for apparel manufacturers. Apparel technologies are advancing for the production of customized garments, providing satisfactory fit for individual customers. For example, Gerber Technology, Lectra System, Inc., Investronica, and AssystBullmer displayed the ability to execute mass customization principles with a demonstration of the process (Wright, 2000). Apparel CAD/CAM suppliers can provide solutions for the customization of existing garment designs, having advanced technologies such as 3D body scanners, digital printers, and fast automatic cutters.
**Apparel CAD Suppliers with 3D Technology**

Two of the major CAD suppliers, Lectra Systems, Inc. and Gerber Technology, Inc., have partnered with body scanner manufacturers and are linking the body scan system with their existing apparel CAD products for the made-to-measure solution (Gerber Technology, Inc.; Lectra Systems, Inc., 2003). Some of CAD suppliers do not have a partnership with any body scan manufacturer, but they provide a software module for drawing a garment shape onto a 3D model and subsequently flattening the shape into a 2D pattern.

**Lectra Systems, Inc. Made-To-Measure with Tecmath AG. (Human Solution GmbH).** Lectra Systems, Inc., one of leading CAD/CAM suppliers to the apparel industry, provides made-to-measure solutions that offers a wide range of pattern, color, fabric, and fit (Lectra Systems, Inc., 2003). One of the company’s made-to-measure solutions combines its proprietary CAD/CAM software with the 3D body measurement technology developed by its partner, Tecmath AG (Human Solutions GmbH), the German specialist in human body digital simulation software and equipment. With the integration of its partner’s technologies to its CAD/CAM software, the company satisfies the growing demand for customized production (Just-in style, 2003; Techexchange.com, 2003, April).

The body scanner provides automatic determination of body measurements on the basis of video images or on the captured surface of the human body. The determined body measurements or virtual model enable the selection of the best fitting sizes and the production of customized garments for the individual customers (Textile Clothing
Technology Corp., 2003). In the Bobbin Americas Show that was held September 13-15, 2000 at the Atlanta World Congress Center, Lectra Systems, Inc. demonstrated integration of 3D scan measurement data with its ‘Modaris FitNet’ customization software. However, the integrated solution is not yet being used by a customer.

The Lectra ‘FitNet’ system takes a number of steps for customization. A customer selects the style, fabric, and color, in addition to all detail options. Body measurements, taken by hand or with a body scanner, are then entered into the ‘FitNet’ system. A customer's measurements can be sent instantaneously via the internet to the production site. Figure 1 shows that the system calculates the differences between the customer’s measurements and the reference garment in the closest size. Any necessary alterations can be made to the style and the style produced to exact measurements (Textile Clothing Technology Corp., 2003).

Figure 1. Lectra FitNet (Lectra Systems, Inc., 2003)
‘Modaris’, which is used for mass production and custom production, automatically produces the customized style without any input by a pattern designer. A pattern designer can manipulate pattern pieces with fabric color or style automatically using ‘Modaris Expert’ module (see Figure 2).

![Figure 2. Modaris Expert module (Lectra Systems, Inc. 2003)](image)

According to Lectra Systems, Inc., the ‘Modaris Expert’ module automatically transfers alterations and grading to all the pieces involved, and continually checks for the consistency of the pattern pieces with other variations of the style (Lectra Systems, Inc., 2003). In cases where the marker making for the style is done automatically by ‘Diamino Expert’, no conversion is required. The marker is then ready to be cut quickly by ‘TopSpin’, an automated fast cutting system (Lectra Systems, Inc., 2003).

**Gerber Technology, Inc. with Telmat Industrie.** Gerber Technology, Inc., a major CAD supplier, provides integrated computer hardware and software systems to the apparel industry. Gerber Technology, Inc. defines Made-to-Measure (MTM) and mass customization as custom-made to an individual’s style and fit (Gerber Technology, Inc.,
2003). The company provides several customization tools, including ‘APDS-3D’, ‘Pattern Design’, and ‘AccuMark MTM’.

At the 1999 Bobbin show, Gerber Technology, Inc. demonstrated virtual draping, and a sample program that can transfer a 2D flat pattern to a virtual 3D dress form by using ‘APDS-3D’. The ‘APDS-3D’ is a pattern visualization software licensed by Gerber Technology, Inc. through developer Asahi Chemical Industry Co. Ltd. in Japan (Rabon, 1999). The program integrates patterns created using ‘AccuMark PDS’, a system that enables basic to complex pattern making tasks including grading tools. ‘APDS-3D’ reduces the time needed to create the most accurate, realistic draping effects, and communicates these results with ‘AccuMark Pattern Design’ for actual pattern design. For example, one can quickly drape a flat pattern on the dress form and then easily modify the graded pattern in 3D (see Figure 3).

![Figure 3. AccuMark Pattern Design and APDS-3D (Gerber Technology, inc., 2003)](image)

As shown in Figure 3, the ‘APDS-3D’ can import fabric designs from Gerber’s ‘Artworks Studio™’ program, and it is also possible to create a dress form from actual customer body measurements (Gerber Technology, Inc., 2003). The actual customer
body measurements can be extracted from a body scan system. According to an ARN report of the 2000 Bobbin Americas show in Atlanta (Safar, M., 2000), Gerber Technology, Inc. was promoting mass customization and had set up an end-to-end production line that started with the 3D scanner for measurement extraction with the [TC]² Image Twin scanner. At the Bobbin show, Gerber Technology, Inc. demonstrated 3D scan measurement data extraction and the possibility of creating customized patterns with the measurements.

In 2003, Gerber Technology, Inc. developed a partnership with Telmat Industrie in order to demonstrate the ability of its ‘AccuMark MTM’ software to accept scanned body data from any of the leading body scanning platforms (Arthurs, J., 2003; Gerber Technology, Inc., 2003). The ‘AccuMark MTM’ software assists fast data entry and processing of information for order entry to plotted or cut markers, all in one step (see Figure 4).

![Figure 4](image)

Figure 4. AccuMark MTM system (Gerber Technology, Inc., 2003)
Figure 4 shows the ‘AccuMark MTM’ system and a body measurement process example. The system consists of an ‘AccuMark’ PC configuration. As shown in Figure 4, the MTM order entry form includes order information, body measurements, garment descriptions, alterations, and preferences. Customer orders can be submitted manually by the user on the PC, or automatically from a main frame, or other network connection. The ‘AccuMark’ orders and altered patterns are automatically created through the MTM software. Markers are then made automatically and used for processing plots and cuts (Gerber Technology, Inc., 2003). The Gerber’s ‘AccuMark’ system with 3D technologies shows potential to reduce the time needed for providing modified individual designs in a mass customization environment.

**Investronica, Sistemas.** Investronica Sistemas has implemented the mass customization process by linking the points-of-sale to manufacture via the Internet, and the company provides ‘Inves Made-to-Measure’ that generates the patterns and marking using the ‘Invesmark Futura’ suite (Investronica Sistemas, 2003). The ‘Invesmark Futura’ suite includes Fashion Builder that assists customization with 3D design presentation. The ‘Fashion Builder’ works with a parametric dummy shape that can be altered by editing pre-set body parameters.

The ‘Fashion Builder’ has the following main components: ‘PGSmodel’, ‘V-Stitcher’, ‘Body Garment’, and ‘InvesPM’ (Wentzel, 2003). While ‘PGSmodel’ has a macro function that makes it possible to industrialize the 2D design patterns, ‘V-Stitcher’ and ‘Body Garment’ assist 3D design. ‘V-Stitcher’ offers 3D representation of garments, and ‘Body Garment’ enables the creation parametric clothes dummies. The parametric
clothes dummies fit the anthropometrical measurements of the target population. Once the clothes dummies have been created, ‘Body Garment’ enables the design of garments to display on the screen in 3D. It specifies the relevant suitability and style parameters with a graphical and intuitive method. The ‘Body Garment’ can automatically produce the bi-dimensional patterns that correspond to the designed garments (Investronica Sistemas, 2003). Figure 5 shows the ‘Invesmark Futura suite’ with ‘Fashion Builder’ components.

![Figure 5. Invesmark Futura suite with Fashion Builder (Investronica Sisemas, 2003)](image)

As shown in Figure 5, using these tools, a designer can draw garment shapes with seams onto the figure. The individual pattern pieces are then defined and flattened by the software to a 2D pattern. Initially, the garment would be skin-tight, so parameters have to be entered to define the gap between body and garment. The garment can be displayed
on the figure with a chosen fabric. Because the original garment shape is a 3-dimensional grid, the fabric is simply stretched over this grid and therefore, also appears in a 3D effect (Wentzel, 2003). All the product information can be organized with ‘InvesPM’ that is a PDM (Product Data Management) tool. According to Investronica Sistemas, these tools aid in reducing time to market and improving product quality (Investronica Sistemas, 2003). This can be interpreted that the Investronica Sistemas approaches its idea of mass customization with ‘Inves Made-to-Measure’ tool in a 2D and 3D bi-directional design manner, linking information via Internet.

**OptiTex USA, Inc. (Scanvec Garment Systems).** Like other CAD suppliers, OptiTex USA, Inc. also focuses a 3D virtual design and information management via the Internet. In 2001, OptiTex USA, Inc. introduced 3D4B2B that is a web enabled 3D virtual fit modeling application at the Sewn Products Expo at the Los Angeles Convention (OptiTex USA, Inc., 2003; Techexchange.com, 2001, March 13). The 3D4B2B might have the potential for bi-directional design between 2D pattern and 3D model.

The 3D4B2B can accept 2D flat patterns from a variety of CAD systems, and the 2D patterns can be draped onto a user definable 3D model that is displayed on a B2B website. The 3D product can be then flattened out to 2D patterns for production (Techexchange.com, 2001 March 13). The 3D4B2B can be plugged into an existing B2B website (OptiTex USA, Inc., 2003), and it can be used in conjunction with a variety of PDM systems and body scanner systems (Techexchange.com, 2001 March 13). It might allow an entire supply-chain to preview the product, and share collaborative input.
A different approach to 3D design or pattern modification is provided by OptiTex USA, Inc. For example, OptiTex Runway™ is a realistic cloth simulation system based on accurate CAD patterns and fabric characteristics (see Figure 6). Figure 6 shows the simulation model with OptiTex Runway™. Different fabrics and stitch properties can be entered, making the cloth simulation. Stitch properties such as gathering, shrinkage, strength, width and texture can be applied. A tension map illustrates clearly in red where the cloth is under tension and green where the cloth is relaxed (Wentzel, 2003).

![Figure 6. Simulation model with OptiTex Runway™ (OptiTex, USA, Inc., 2003)](image)

Modulate is an interactive parametric Made-to-Measure engine (OptiTex USA, Inc.,2003). It includes a highly detailed parametric mannequin with over 40 precise adjustable body measurements. The measurements can be input directly from a body scan, or users can create specific base size mannequins (OptiTex USA, Inc.,2003; Wentzel, 2003).
Each parametric style fits a particular set of dimensions that belong to specific people or represent particular manufacturing requirements. For example, a parametric jacket can be defined using dimensions annotated as "Shoulder", "Bust", "Waist", and "Hips" (See Figure 7). Modulate will shape the jacket to fit these four dimensions (OptiTex USA, Inc., 2003).

![Figure 7. OptiTex modulate for made to measure (OptiTex USA, Inc., 2003)](image)

As shown in Figure 7, each modification to the jacket can be visualized interactively when changing names and values. Every variable used for a specific style can be saved in a 'Variable library' for future use. All specifications, dimensions, styles, and orders are maintained in a standard database for repeat orders, and each step of the operation is visualized while defining the parametric model (OptiTex USA, Inc., 2003).
According to OptiTex USA, Inc. (2003), patterns can be imported virtually from any CAD system for the OptiTex modulate. The supported file formats include: DXF, AAMA, ASTM, NC, HPGL, HPGL-2, and MicroJet. A unique list of Import/Export capabilities might make OptiTex software a flexible CAD system for sewn products (see Figure 8).

![Figure 8. Import file format (OptiTex, USA, Inc. 2003)](image)

OptiTex USA, Inc. is convinced that the OptiTex Runway™ 3D would reduce product development time and cost of multiple iterations of sample garment production. It would enhance the quality of products due to the use of an accurate modeling system, and analyzing fabric behavior simulation (OptiTex USA, Inc., 2003).

**Assyst’s Draping 3D simulation.** Like other CAD suppliers, Assyst also shows 3D draping simulation technology for virtual garment sampling. Even though there was no evidence of either linking with 3D body scan measurements or suggesting parametric
sizing systems, the 3D draping simulation with ‘graph.assyst’ might be an example of developing 3D tools for customization.

According to the company (Assyst, 2003), the module and its tools are integrated into the core product, and the functionality reflects the core tools reducing training time or production time. The 3D draping simulation allows users to see immediately the results of an idea, and the users can make spontaneous decisions on adoption of the concept by visualizing new product ideas repeatedly in an unlimited number of fabrics.

The realistic simulations might assist for the development of new products in an efficient way by transforming any 2D image into a more realistic 3D draping simulation. This type of 3D simulation for designing is more often provided by virtual design software suppliers.

**Virtual Try-On Capabilities in 3D**

As interest increases in garment customization, e-commerce, and available advancing 3D technology, virtual design has been considered an important part of the apparel design customization tools. Virtual design software suppliers show evidence of capability with designing in 3D for mass customization by providing user interaction via internet.

**Browzwear.** Browzwear provides real-time 3D solutions to the growing business-to-business and e-commerce markets for online apparel segments. Browzwear developed virtual modeling and design products such as ‘V-Stitcher’ and ‘V-Styler’ for these solutions. The company displayed ‘V-Stitcher’ and ‘V-Styler’ in conjunction with Investronica, a developer of CAD design tools, and with Koppermann, a developer of
software solutions for virtual visual product development at the IMB 2003 trade show (Techexchange.com, 2003, March).

Browzwear’s ‘V-Stitcher’ is based on 3D visualization that enables users to create a virtual garment from a 2D pattern over a 3D body image (Techexchange.com, 2003, March). The latest developments include a parametric avatar of children, a fitting analysis tool that displays the exact stretch of every grid element over the body, improved simulation accuracy, 3D design capabilities, simplified and improved fabric testing methods, special simulation capabilities for undergarments and swimwear, and integration to other applications (Techexchange.com, 2003, March).

This capability may revolutionize the design process by allowing the entire supply chain to visualize products and share input simultaneously. The adoption of its 3D simulation technology has already been shown in the apparel industry. For example, ‘V-Stitcher’ in use at Benetton transforms 2D patterns into virtual 3D simulations of completed garments with multi size grading over a virtual body (see Figure 9).

Figure 9. Browzwear’s ‘V-stitcher’ (Tait,N. 2001)
The transformed 2D pattern is based on the output of all industry standard CAD packages, and the 2D pattern is modified to create an immediate 3D display of the garment. The modifications can also be communicated over the Internet for immediate viewing and approval (Tait, 2001). As shown in Figure 9, texture mapping capabilities enable photo quality representation of fabric, seams, prints and colors. Changing the fabric characteristics, such as chiffon to a heavy knit, results in virtual draping behavior. The 3D model can be viewed to 360° and to zoom in on the garments to see fabric or stitching detail (Tait, 2001).

Browzwear developed C-me for virtual fit application in the Business-to-Consumer (B-to-C) environment by allowing Internet shoppers to dress their own virtual 3D image. Retailers are already using the software on their websites. For example, Browzwear’s C-Me was launched commercially in 2001 with the XOXO site, and allows customers to “try-on” clothes over the Internet or at an in-store kiosk (Speer, 2002). The application works quickly and also preserves the privacy of the user, whose body is created by adding body measurements on the user’s own computer, not on the server (Speer, 2002).

The company is convinced that the number of returned garments can be reduced by using its 3D virtual design software (Tait, 2001). The 3D virtual design simulation detail can reduce product approval and production times by allowing the entire supply chain to visualize products and share input simultaneously (Stitch magazine, 2000). This results in accelerating time to market and ultimately increasing profitability.
**My Virtual Model (MVM).** In 2001, ‘My Virtual Model™’, so far the most commercially successful try-on technology, offered ‘My Virtual Model Dressing Room’ and ‘My Virtual Model Fit’, which enabled users to try on clothes as well as receive size and fit recommendations. The ‘My Virtual Model™’ is available on sites including Lands’ End, Inc.; Nutri/System; Lane Bryant; Crossing Pointe; Kenneth Cole; WeddingChannel.com; Orvis; Plussize.com; and FUBU (Speer, 2002).

My Virtual Model, Inc. believes that 3D visualization technology improves online profitability. For instance, My Virtual Model, Inc. and Lands' End Inc. have released data confirming that the use of My Virtual Model's visualization technology by Lands' End online shoppers had a positive impact on key profitability indicators, including conversion rates and average order value (AOV). According to the data, the average order value (AOV) of shoppers who used their virtual model was 16% higher than the AOV of those who did not use a model to shop online at Landsend.com. Online shoppers who used models were 19% more likely to purchase items than shoppers who did not use the model (Techexchange.com, 2001, March 26).

This indicated that the 3D virtual model technology assists consumers’ confidence in their final purchase decision by giving them access to an interactive virtual try-on session. This might result in higher profit and less risk of returning garments online.

**FitMe.com with 3D Body Scan.** FitMe.com, established in 1999, is also developing a 3D model and techniques in apparel simulation for virtual try-on technologies that include the reality of the model to provide mass customization solutions to the apparel industry (Speer, 2002). Since fit problems are still the biggest reason for
hesitation in buying apparel online and also account for the majority of returns (Speer, 2002), FitMe.com developed its first commercially available product, Size Genie. The Size Genie is a web-based software application that allows individual consumers to determine their fit and optimal sizes across hundreds of brands of clothing (Speer, 2002). The Size Genie application is available in a consumer version, which can be accessed at www.fitme.com, and in a retailer version, which integrates with a retailer’s web site.

The company’s focus is in driving accurate measurements from the 3-D model, and it has a partnership with a body scanner supplier, Hamamatsu, in Japan (Speer, 2002). FitMe’s specialty is in being able to drive measurements from the scanned model in a much more accurate way. According to the company (Speer, J. 2002), a body scanner provides all possible measurements with a scanned picture, but the raw measurement data has to be translated to actual body measurements for apparel. The complex translation process is called OCR (Optical Character Recognition) technology, and FitMe is developing a product for the body scanning arena using the similar method of OCR technology that translate the image into a form (Readsoft, 2003).

This shows virtual design suppliers and CAD suppliers are adopting the 3D body scan technology for customization and fit solutions for the apparel industry. According to the study of three dimensional body scanning systems for apparel mass customization (Xu, et. al, 2002), 3D body scanning systems enable apparel manufacturers to provide custom design services to consumers seeking personal fit garments.
Available 3D Body Measurement Technology for Apparel Customization

Body Scan systems can be found in a variety of areas such as statistical analysis, modeling, animation, medicine, anthropometry, and apparel. Leading systems can be found from Japan, the United Kingdom, Germany, France, and the United States. Scanners are listed in Table 1, according to the type of technology used to capture the image. The listed scanners were found in research of 3D body scanning systems with application to the apparel industry in 2000 (Istook & Hwang, 2000).

Table 1. 3D scanning systems by type (Istook & Hwang, 2000)

<table>
<thead>
<tr>
<th>Light Based Systems</th>
<th>Laser Based Systems</th>
<th>Surface Tracing Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company</td>
<td>Product</td>
<td>Company</td>
</tr>
<tr>
<td>Hamamatsu Photonics</td>
<td>Body Lines Scanner</td>
<td>Cyberware, Inc.</td>
</tr>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Loughborough</td>
<td>LASS</td>
<td>Tecmath AG (Human Solutions GmbH)</td>
</tr>
<tr>
<td>University</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(TC)^2</td>
<td>2T4,3T6</td>
<td>Vitrionic GmbH</td>
</tr>
<tr>
<td>Wicks and Wilson</td>
<td>TriForm, TriForm</td>
<td>Hamano Engineering Co.</td>
</tr>
<tr>
<td>Ltd.</td>
<td>BodyScan, TriForm3 (Torso Scan), TriForm2 (Headscan), TriForm1</td>
<td>Ltd.</td>
</tr>
<tr>
<td>Telmat Industrie</td>
<td>SYMCAD 3D Virtual model</td>
<td>Polhemus CSC Provider</td>
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<tr>
<td>Turing</td>
<td>Turing C3D</td>
<td>3D Scanners</td>
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<tr>
<td>Puls Scanning</td>
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<tr>
<td>System GmbH</td>
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<tr>
<td>Cognitens Ltd.</td>
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</tbody>
</table>

After the research period in 2000, scanning systems were updated, or new scanning systems entered the market. For example, Intellifit Corp.’s scanner is available
for apparel applications, and it uses a radar wave to scan a body. Tecmath AG changed to Human Solutions GmbH for Vitus products in Germany.

An early model of a 3D body scanning system developed by Japanese researchers consisted of a mechanical sliding gauge to trace the horizontal and vertical curves of a human body (Yu, 1999). According to Yu (1999), the early non-contact measuring device, a silhouetter, produced a 2D photo of a body contour. It consisted of a booth with large grid wall, a series of florescent light tubes, and an instant camera. In 1984, Wacoal developed a computerized silhouette analyzer that could electronically process data on the contours of an object (Yu, 1999). It was a very similar idea to 3D body scanning systems in terms of using a non-contact method with light sources.

Current three-dimensional body scanners capture the outside surface of the human body by using optical techniques, in combination with light sensitive devices, most often without physical contact with the body. Body scanning systems consist of one or more light sources, one or more vision or capturing devices, software, a computer system, and a monitor screen. The primary types of body scanning systems are laser and light. Surface tracing systems also exist. However, these are not currently used for capturing the shape of human bodies. Both white light and laser scanning systems follow four main process steps (see Figure 10).
Figure 10. A flow process of 3D body scanning systems

First, an object is illuminated and scanned by mechanical motion of the light sources, either white light or laser. Second, CCD cameras detect the reflected patterns from the object. Third, the displacement of the structured light pattern is used to calculate the distance from the subject to the CCD camera. Finally, software inverts the distance data to produce a three-dimensional representation.

According to Kaufmann (1997), in the final step of the software inversion, a certain amount of redundancy is needed in the measurements to overcome shadowing of arms and ears. For the apparel industry, measurement data from the 3D body scanning systems could be stored in a customized card and integrated into apparel CAD systems. Most 3D body scanning systems currently available differ slightly by the light source or their scanning methods. They can be categorized based on three different operating
principles: light based scanning systems, laser scanning systems, and LED with PSD systems.

**Light Based Scanning Systems**

Most white light 3D body scanning systems with grid lines have been developed from the shadow moiré technique. Hong Kong Polytechnic University, Triform from Wicks & Wilson, Ltd., and [TC]² are examples of white light scanning systems (Yu, 1999). The white light sources are usually referred to as Halogen lamps.

The body scanner developed by the Institute of Textiles and Clothing at the Hong Kong Polytechnic University uses projection moiré topography (Yu, 1999). In the moiré technique, a grid plane, camera, white light source, and operating system are used (Lovesey, 1974; Yu, 1999). The use of grid lines is a main difference from other scanning principles. While a human body is being scanned, we can usually recognize the horizontal grid lines on the object.

According to Lovesey (1974), moiré techniques had two different methods, additive moiré methods and subtractive moiré methods. In additive moiré methods, the object surface and a reference plane are illuminated at an angle by a straight-line grid projector and moiré fringes are formed between the distorted body lines and the straight line on the reference (see Figure 11a).
In subtractive moiré methods, a point of light casts a shadow of a coarse grating on to an object and the fringes are formed between the distorted shadow, as seen from the camera position and the grating that is illuminated by light reflected from the body (see Figure 11b). The subtractive moiré method has reported a disadvantage of divergence errors (Lovesey, 1974). For this reason, most current light based scanning systems seem to be developed from the additive moiré methods with a straight line from a grid projector.

According to a study by Arai, Yekozeki, and Yamada (1991), the grid illumination type of moiré method is operated more easily than the grid projection type. Even though it is more difficult to automate the grid illumination type, they strongly suggested that this method be used in automatic measurement systems since it is more precise and compact than the grid projection type.
The following Figure 12 shows the arrangement of a shadow moiré body scanning system developed by Hong Kong Polytechnic University. The following equations were used in the development of their system.

\[
\frac{OP}{OC} = \frac{RQ}{OR} \quad \frac{Zn}{L} = \frac{ng}{d-ng} \quad Zn = \frac{ngL}{d-ng}
\]

- \( P \) = points of intersection \( h \) and \( k \)
- \( I \) = image plane
- \( P' \) = a point on \( l \) lies on a moiré fringe
- \( k \) = light projection line
- \( h \) = line of sight observation intersect
- \( g \) = space between two grid lines
- \( n \) = line family of intersection of

**Figure 12.** The shadow moiré system developed by Hong Kong Polytechnic University (Yu et al., 1997)

The camera is used to produce a good resolution of fringes. It is necessary to arrange the distance between camera and grid because it is related to production of a bigger \( L \) and wider fringe interval (Yu et al., 1997).

Usually light based 3D scanning systems, which partially or fully adapt moiré techniques, show problems with surface reflectance and noisy fringes. There are still limitations on accuracy of measurements due to the use of light reflectance and its translucency in the moiré method (Kafri & Glatt, 1990). A similar problem of forming a sharp shadow is also found with human skin because of its translucency (Yu et al., 1997).
[TC]² had a similar problem, and used matt black paint or a large black cloth during the scanning process to avoid unwanted light reflectance.

**LASS.** One of the earliest 3D body scanning systems was a shadow scanning method developed by Loughborough University in the U.K. The LASS shadow scanner was used in the Human Measurement, Anthropometry and Growth Research Group (HUMAG). Anthropometric surveys throughout Britain have been undertaken to describe the body sizes and shapes of adults. The LASS, 3D automatic body measuring system was aimed at the automation of clothing sizing and design, and applications in manufacturing industries and medicine (HUMAG, 2000).

The Loughborough Anthropometric Shadow Scanner (LASS) differs from other conventional structured lighting approaches in that the object being scanned is rotated. However, according to Bouguet and Perona (2000), the principle of shadow scanners is similar to the most conventional structured lighting systems in that the camera faces the scene illuminated by a halogen light source, and the camera captures images as an operator moves the light so that the shadow scans the entire scene. This constitutes the input data to the 3D reconstruction system.

In the study of format for human body modeling from 3-D body scanning (Jones et al., 1995), the Loughborough Anthropometric Shadow Scanner was chosen as an automated, computerized 3D measurement system based on the triangulation method. The subject stands on a rotating platform and is turned 360 degrees in measured angular increments. A slit of light from each of 16 projectors falls onto the body in a vertical plane that passes through the center of the rotation (see Figure 13).
A column of cameras is used to read the image of projected light. From the camera image of the edge of the light slit, the height and horizontal radii of the body at the vertical plane can be easily calculated. The measured data are 3D surface coordinates of a body in cylinder coordinate form. Images captured from 14 TV cameras are then processed electronically (Jones et al., 1995). The resolution of measurements in the vertical and the radial directions are 1mm and 1.6mm respectively, according to the camera resolution (Jones et al., 1995; Yu, 1999).

In the study of the format for human body modeling from 3D body scanning (Jones et al., 1995), they used a shape matrix for the representation of 3D shapes of the human torso. The shape matrix is a text (ASCII) file containing 16 x, 16 y and one z (height) co-ordinate values on each line (see Figure 14).
N M RY DX DY
X (1,1) Y (1,1) X (1,2) Y (1,2)… X (1,16) Y (1,16) Z (1)
X (2,1) Y (2,1) X (2,2) Y (2,2)… X (2,16) Y (2,16) Z (2)
. .
X (N, 1) Y (N, 1) X (N, 2) Y (N, 2)… X (N, 16) Y (N, 16) Z (N)
N= the number of rows
M= the mode of file, usual 0
RY, DX and DY= transformation information of cross section in X-Y plane

Figure 14. Format of LASS shape matrix (Jones et al., 1995)

The data from the body scanning system can be expressed by using any number of
cross-sections or any number of points in the shape matrix format to facilitate the transfer
of data (Jones et al., 1995).

Telmat Industrie. Telmat Industrie has developed SYMCAD Turbo Flash/3D
body scanning system in the framework of a partnership with the French Navy (Daanen
& Jeroen, 1998; Soir, 1999). According to Daanen and Jeroen (1998), SYMCAD is
categorized as a shadow scanner. As illustrated in Figure 15, during the scanning
process, horizontal grid line shadows are seen on a human body as are usually seen in
shadow scanners.

Figure 15. Shadow grid lines seen in SYMCAD
(Telmat Industrie, 2000)
SYMCAD acquires pieces of information in $1/25^{th}$ of a second. It takes 30 seconds for the cameras to move along the beams and acquire data for the whole body. After computational calculations are made on the formed scanned image, the system is able to generate 70 precise body measurements, and it takes less than 15 seconds for the system to extract this data (Daanen & Kerpen, 1998; Telmat Industrie, 2000). Among the data recorded are traditional measurements used by clothing professionals, such as neck, waist, chest, bust, and hip circumferences.

**[TC]**. The Textile Clothing Technology Corporation ([TC]²) has a 2T4 and a 3T6 scanner. Both scanners have been used at North Carolina State University for developing apparel applications. The [TC]² systems use white light and a triangulation method between camera, projector and a subject (See Figure 16).

![Figure 16. [TC]²’s triangulation between projector camera and subject ([TC]², 2000)](image)

The company developed a Phase Measuring Profilometry (PMP) technique for commercialization ([TC]², 2000). PMP is similar to Moiré light projection techniques, but differs from Moiré data-capture approaches in that it employs a phase-stepping
technique (Paquette, 1996). According to Paquette (1996), this phase measuring profilometry (PMP) method was thought to improve overall image resolution.

The PMP technique uses a white light source to project a contour pattern on the surface of an object. A charge-coupled device (CCD) camera linked to a computer detects the resulting deformed grating. The superimposed projection grating lines interact with a reference grating, forming the fringes. As irregularities in the shape of the target object distort the projected grating, fringe patterns result ([TC]^2, 2000). The PMP method involves shifting the grating preset distances in the direction of the varying phase and capturing images at each position.

A total of four images are taken from each sensor, each with the same degree of phase shift of the projected sinusoidal patterns. Using the four captured images, the phase of each pixel can be determined. The phase is then used to calculate the three-dimensional data points ([TC]^2, 2000).

Figure 17 shows the intermediate output of the PMP process is a data cloud of points for each of the six views (right front, left front, and rear in both the upper and lower part of the body). The individual views are combined by the exact orientation of each view with respect to one another. Scanning a calibration object of known size and orientation is an essential step in this orientation. This is known as system calibration ([TC]^2, 2000).
The points that result from the data set are the raw calculated points without any smoothing or other post-processing. In order for measurements to be extracted, the data must be further processed by filtering, smoothing, filling, and compressing. The PMP method enables faster data acquisition than laser scanning or shadow scanning, but is unable to provide color information ([TC], 2000).

According to Shentu (1995), when analyzing human body images, the 64 color RGB file could be reduced to the two colors of black and white allowing smaller file sizes and easier data analysis. Even though it seems unnecessary to have color information, according to Bruner (2000), the new 2000 model [TC]² has been focused on having colors to meet the demand in the market.

**Wicks & Wilson, Ltd.** Triform is a non-contact 3D-image capture system from Wicks and Wilson, Ltd. in the United Kingdom. A variation of the “Moiré fringe technique” with white light in the form of a halogen bulb is used to capture the 3D shape
of an object. The 3D shape is a colored point cloud on the monitor screen that looks similar to a photograph of the subject (see Figure 18).

Figure 18. Triform from Wicks & Wilson, Ltd. (Wicks & Wilson, Ltd., 2000)

Triform has already been tested in a large garment sizing survey in the UK organized for Marks and Spencer (Yu, 1999; Wicks & Wilson, Ltd., 2000). Wicks & Wilson, Ltd. (2000) anticipated that Triform would increase sales, enable virtual displays at point-of-sale and in catalogue shopping.

**Other Light Scanning Systems.** Other light based scanning systems include the 3D moiré body scanner from the Hong Kong Polytechnic University and the PULS scanning system. Usually light structure scanning systems are cheaper than laser scanning systems. However, according to Yu (Yu, 1999), data from light based scanning systems is less precise because the light spot is larger. Figure 19 shows the 3D moiré body scanner developed by the Institute of Textiles and Clothing at the Hong Kong Polytechnic University. The system contains a light source, two identical grid planes
with thirty line pairs, a set of projection lens, an image formation lens and digital camera. Contour moiré fringes show the 3D shape of the object (Yu et al., 1997).

![Image](image.png)

**Figure 19.** A shadow moiré scanner at Hong Kong Polytechnic University (Yu et al., 2000)

The PULS scanning system developed in Germany consists of a light source, a CCD camera, a PC screen, and four mirrors. A CCD camera is connected to a personal computer and Camera projection is done between the mirrors (PULS GmbH, 2000). This projection area is changeable to any room situation because mirrors can be arranged (see Figure 20).

![Diagram](diagram.png)

**Figure 20.** PULS scanning system’s arrangements (PULS GmbH, 2000)
Photographs of the human body in front and side views are taken simultaneously by a patented mirror arrangement. The use of mirrors is different from other light structure scanning systems and may provide flexibility in limited space (PULS GmbH, 2000).

**LED with PSD Scanning Systems**

The Light Emitting Diodes (LED) with Position-Sensitive Detector (PSD) method is used in the Hamamatsu body scanning system (Hamamatsu Photonics, 2000). According to Kaufamann (1997), an infrared LED is pulsed and passed through a projection lens to be reflected from an object onto a photograph. The light is then collected by a second lens and focused onto a detector (see Figure 21). A centroid, a point in the system, has the same dimension of points weighted mean of coordinates. The weight is determined by the density function of the system. In this system, a position sensitive detector (PSD) is used to determine a centroid’s position (Kaufmann, 1997).

![Diagram of LED with PSD systems](image)

*Figure 21. LED with PSD systems (Kaufmann, 1997)*
As shown in Figure 21, the light reflected from the object strikes the photodiode, and the PSD. Photoelectrons generated in the photodiode diffuse toward both electrodes. A combination of mechanical scanning, multiple sensors, and electro-optic scanning processes are used to produce a three dimensional image of an object, because a segmented PSD provides only one distance at a time (Kaufmann, 1997).

**Hamamatsu Photonics.** The Hamamatsu Body Line (BL) scanning system uses near infrared LED (Light Emitting Diodes) to obtain scan data (Hamamatsu Photonics, 2000; Paquette, 1996). According to Hamamatsu Photonics (2000), originally the BL scanner was developed for use in Japan scanning the women’s upper torso where wearing undergarments. Hamamatsu Photonics has a branch office in the USA to develop the software program and has been supporting schools in the UK, Germany and Japan to aid in the development of their body scanning system. The BL Scanning system is being used in the University College of London for human modeling research (Hamamatsu Photonics, 2000). They have also worked with the Natick Soldier Center to compare their Body Line (BL) scanning system with the Cyberware system used at Natick (Hamamatsu Photonics, 2000; Paquette et al., 1998).

The Hamamatsu Body Line (BL) scanning system was developed to extract three dimensional body data using body landmarks and having less missing data than other previously developed systems (Hamamatsu Photonics, 2000; Paquette, 1996). Light is pulsed through a projection lens onto the subject. Near infrared light is reflected from the subject being scanned and is collected by the detector lens. The detector lens is a
combination of spherical and cylindrical lenses that generate a slit beam on the Position Sensitive Detectors (PSD) (Hamamatsu Photonics, 2000; Kaufmann, 1997).

According to Kaufmann (1997), the lateral-effect photodiode, also known as a position-sensitive detector (PSD), is used to determine the position of the centroid and two PSDs are used to compensate for shadowing of one of the detectors. Eight sensors are mounted on a U shaped rail (Hamamatsu Photonics, 2000). Measurements are extracted from the raw data for a specified set of measurements (see Figure 22).

![Figure 22. Hamamatsu BL scanner’s 8 scanning head (Hamamatsu Photonics, 2000)](image)

**Laser Based Scanning Systems**

Laser scanning systems are distinguished from white light scanning systems, which use moiré principles (Dalton, 1998; Shentu, 1995). Usually, laser scanning systems, such as WBX, WB4, and Voxelan, do not show horizontal grid shadow lines on an object and do not require a closed dark room to capture the shadow (Paquette, 1996).

According to Paquette (1996), the laser scanning process has the following processes. The scan subject wears form-fitting briefs or bicycle/running shorts during the
process as the scanner projects a line of laser light around the body. The laser line is reflected into cameras located in each of the scan heads. Data is obtained using a triangulation method (Clark, 1997; Paquette, 1996) in which a strip of light is emitted from laser diodes onto the surface of object being scanned, and then viewed simultaneously from two locations using an arrangement of mirrors.

Viewed from an angle, the laser stripe appears deformed by the object’s shape. CCD sensors record the deformations and create a digitized image of the subject. The cameras positioned within each of the four scanning heads record this surface information when the heads move vertically along the length of the scanning volume. The separate data files from each scanning head are combined in the software to produce a complete integrated image of the scanned object. Unlike other scanning system methods, the laser scanner generates RGB color values, a process of identifying color-coded landmarks for data extraction after scanning (Paquette, 1996). The scanning process follows a non-contact sensing method in which a sheet of laser light is projected onto an object (see Figure 23).

![Diagram of laser scanning](image)

**Figure 23.** Strip scanning mode and depth measured by triangulation (Recreated figure from Clark, 1997)
As shown in Figure 23, the resulting 3D-curve stripe is observed through one or more imaging sensors, such as CCD cameras. The camera is arranged so that the image of the stripe intersects each image row or column uniquely, and the range Z can be linked to one image co-ordinate (Clark, 1997). In this system, a scanning control software is also required. Optical laser triangulation is a reliable non-contact technique used in rapid prototyping of industrial parts or in various applications such as gauging, profiling and 3D surface mapping (Clark, 1997).

According to several researchers (Clark, 1997; Dalton, 1998; Shentu, 1995; Yu, 2000), laser based scanning systems were reported to have good resolution, low measurement noise, and high accuracy. However, laser scanning systems are more expensive than other scanning systems.

**Cyberware, Inc.** Cyberware, Inc. developed WB4 and WBX scanning system for the apparel industry, garment designers, anthropologists, automotive designers, furniture designers, computer game developers, and medical applications (Cyberware, Inc, 2000). The U.S. Army Natick RD &E Center uses the Cyberware system to develop and analyze body shapes for armor coverage and for other military uniform clothing. The ARN-SCAN, also called Natick-SCAN (NS), was created using toolkits developed by Cyberware, Inc. (Paquette et al.,1998). The WB4 system is controlled by Cyberware's Cyscan software which performs basic graphic displays (see Figure 24).
The software is written in C++ and Tcl/Tk. The scan data is convertible to VRML for web-based applications (Cyberware, Inc., 2000). It was designed and manufactured as a portable tool for highly versatile and accurate scientific applications and has proven invaluable in collecting the data necessary to develop the measurement extraction capabilities required for accurate recruit uniform sizing.
In 2000, Cyberware, Inc., developed the WBX version of the WB4 scanner since the scanner has expensive features not necessarily needed on the recruit issue line and requires skilled personnel for its setup and operation. The WBX version of the scanner collects all of the data required for clothing measurement extraction with a substantial reduction in complexity, size and cost. The WBX system scans in half of the time of the WB4 and reduced the cost by 57% (ARN, 2000). It has a simpler assembly and operation than the WB4 system and includes a task optimized motion system. The WBX was tested at the Marine Corps Recruit Depot in San Diego during February 2000 (ARN, 2000).

**Tecmath AG (Human Solutions GmbH).** Tecmath AG is a German company that does consulting in ergonomic product design, vehicle design, work place design, anthropometric databases, and statistical analysis. Tecmath AG also supports clothing and shoe design, Made-to-Measure, and ergonomic anthropoids. The company develops software and hardware related to ergonomics and garment measuring systems in their division of human modeling. This company developed the RAMSIS, Contour, Move, and Vitus systems (Tecmath AG, 2000).

The RAMSIS system is directed at virtual product design and ergonomic analysis. It was developed in response to the German Automotive Industry and is now used by 60% of the automotive industry worldwide. RAMSIS is Tecmath AG’s ergonomic tool that takes only 1.3 seconds to scan an object. Contour and Vitus are Tecmath’s measurement tools and Move is an optical infrared marker system with automatic tracking of movement (see Figure 25) (Tecmath AG, 2000).
Contour and Vitus have been used to develop fit of army clothing and to select sizes from tables which contain basic body dimensions for companies, such as KAKA, DoB, and Bundeswehr (Tecmath AG, 2000).

Contour is a camera based measuring system and a 2D scanner that calculates body dimensions at a relatively low price and in less than two minutes. It automatically classifies clothing sizes and interfaces with pattern design systems, such as Gerber Technology and GRAFIS. The Contour system consists of lighting tubes, a calibration plate, a CCD camera, and a frame grabber. It operates on a Windows 95 platform and a standard PC (Tecmath AG, 2000).

**Vitronic GmbH.** Vitronic GmbH has been developed Vitus Pro, Vitus Smart, and the PEDUS 3D foot scanner. Vitus is Vitronic GmbH’s 3 Dimensional optical scanning system that also automatically calculates body dimensions. The measurement method used is optical triangulation with laser, using an eye safe laser (class 1) and CCD cameras, traveling vertically. It has an automatic calibration facility and an option for color texture (Vitronic GmbH, 2000).
Obtained measurement data from Vitus Pro is used for antropometric research, rapid prototyping and ergonomic research design with RAMSIS in Tecmath AG. Like all Vitus products, Vitus Smart operates with the light stripe method. Figure 26 shows that Vitus automatically calculates body dimensions.

Figure 26. Vitus Pro 3D scanner (Vitronic GmbH, 2000)
The PEDUS, 3D optical foot scanner, is specialized for measuring feet within seconds to produce the best fitting shoe sizes for customized manufacturing (see Figure 27). It might be possible for individual customers to order made-to-measure shoes.

![PEDUS optical foot scanner](image)

Figure 27. PEDUS optical foot scanner (Vitronic GmbH, 2000)

**Hamano Engineering Co. Ltd.** Hamano Engineering Co. Ltd. develops VOXELAN, which is non-contact, optical 3D scanning system that scans the body with a safe laser. It was originally developed by NKK in Japan and later taken over by Hamano Engineering Co., Ltd. in 1990. The VOXELAN has been used for various purposes, in addition to measurement of the whole human body. The VOXELAN is used for whole body measurement, face detail, and wrinkles. They provide very precise information in a range of resolutions from 0.8mm for the whole body to 0.02mm for wrinkles (Hamano Engineering Co. Ltd., 2000). Data is obtained from the measured shape data with exact one-to-one correspondence. Figure 28 shows measurement points can be defined on the image displayed on the screen. Plaster figures are generated from the measured shape data as cyber space representations. An object is measured from the composition of the front and back data. A birds-eye view of a wired form of the object can also be obtained (See Figure 28).
Multiple sections can be represented on the same coordinates. The perimeter and area of a cross section of an object can be measured, as well as a diameter across its sides and a diameter across its front and back (See Figure 29).

Figure 28. VOXELAN image process (Hamano, 2000)

Figure 29. VOXELAN multiple sections (Hamano Engineering Co. Ltd., 2000)
Figure 30. Measurement of a horizontal section and a longitudinal section (Hamano Engineering Co. Ltd., 2000)

The measurements of a longitudinal section can be obtained in the same manner as used for the measurements of a cross (horizontal) section (See Figure 30). From the measurements, solid shapes of scanned objects are mapped with colors corresponding to the heights varying from the reference position (Hamano Engineering Co. Ltd., 2000).

Other Laser Scanning Systems. Other Laser Scanning systems include FastScan and Model Maker, and Reverse. 3D Scanners Ltd. in London has developed products for modeling objects such as Model Maker and Reverse, which are well known in the automobile industry for measuring and modeling (Clark, 1997).

Polhemus CSC Provider developed FastScan to aid in analyzing the movement of objects. The resulting point cloud and virtual image data files can be integrated into CAD systems that are used in industrial design (Clark, 1997; Dalton, 1998). However, they do not have applications for use in the apparel industry.
Radar Wave Scanning System

Intellifit Corp. Intellifit Corp., founded in 1999, is a technology company offering pattern generation solutions that improve the fit of ready-to-wear clothing, and support custom made-to-fit clothing for apparel brands, retailers, and manufacturers (Intellifit Corp., 2003). Intellifit’s scanner operates with the same radar wave technology as a cell phone, but with only 1/600th of the power. This operates on safe, low power millimeter wave technology that is similar to technology being developed for airport security screening.

A customer can remain fully clothed and only needs to stand still for about 10 seconds while a vertical wand circles the customer’s body. The wand reports data points back to Intellifit software, which then converts the data into accurate measurements of the customer’s body. Only about 36 square feet are required for a scan booth’s space (Intellifit Corp., 2003).

Current Standards of Body Measurements and Determining Landmarks

Current Body Measurement Standards for Apparel

Current body measurement standards for apparel include ASTM (American Society for Testing and Materials) and ISO (International Organizational for Standardization). ASTM standards incorporate anthropometric surveys by the U.S. Army and the U.S. Navy and include current information from apparel manufacturers and retailers (Workman & Lentz, 2000). ISO is a world wide federation of national standards bodies (ISO member bodies). International Standard ISO 8559 was prepared by

ASTM D 5219-99 standard terminology relating to body dimensions for apparel sizing is under the jurisdiction of ASTM Committee D-13 on Textiles and is the direct responsibility of Subcommittee D13.55 on body measurement for apparel sizing. The standard terminology in ASTM refers to ISO standards: ISO 8559 relating to garment construction and anthropometric surveys for body dimension and ISO 3635 relating to size designation of clothes, definitions and body measurement procedures (ASTM, 1999). These two standard body measurement methods are based on a traditional anthropometry measurement method (Clauser et al., 1986).

Even though these two standards are available for apparel sizing, a wide range of different body measurement terminology and methods have been used in the apparel industry. However, insufficient previous research has been conducted to understand the limitation of the measurement terminology and method for apparel applications.

**Problems with Standards for 3D Body Scan Data**

A body scanning technology that has advantages of accuracy, consistency, and speed in the measuring process is a beneficial technology for the apparel industry in the development of customized garments. A body scanning system obtains an infinite quantity of raw data from the scanned object, and it can extract any necessary subset of body measurement data from the raw data (Simmons, 2001).

To extract the measurement data from the infinite quantity of raw data, a body measurement extraction software program is necessary. Some body scanning systems
use their own automated extraction software programs for selection of the data.

Automated measurement extraction offers an advantage over manual digitization given the increased speed and reduced data processing cost, especially for large data sets (Paquette et al., 1996).

According to the study of Automated extraction of anthropometric data from 3D images (Paquette et al., 1996), examples of existing software packages that incorporated automated data extraction include: the ARN-SCAN software developed under the DLA-ARN program, the BL scanner software developed by University College London under sponsorship of Hamamatsu Photonics; and the Body Measurement System (Scanner & Software) created by the Textile Clothing Technology Corporation [TC]² (Paquette et al., 1996).

Some body scanning systems do not have automated extraction software. For example, Vitronic GmbH has developed its own software for visualization and manipulation of 3D scans that allows visualization of up to 16 Million triangles and 3D points, processing of textures, and data export in various formats, such as VRML and JPG (Vitronic GmbH, 2000) but Vitronic has been written to manually, not automatically, extract anthropometric measurements from pre-marked digitized images (Paquette et al., 1996).

To develop a software program for extraction of body measurements for apparel applications, developers and researchers need specific semantics (meaning) and syntax (rules) of the body measurements for specified applications. In the beginning of the body scanning system development, most research (CAESER, 1999; Paquette et al, 1998) used
anthropometric measurement methods since they were not focused on only apparel applications.

Some body scan developers are interested in apparel applications and used standards developed for apparel applications such as ASTM and ISO. For example, Hamamatsu Photonics and Telmat Industrie use ISO body measurement standards for size selection or apparel applications. Size selection tables have been developed based on ISO 8559 (Hamamatsu Photonic, 2000). Size selection tables in SYMCAD are based on ISO 8559 (Telmat Industrie, 2000). Telmat Industrie has demonstrated how measurements could be stored and delivered to the ultimate user with their SYMCAD Body Card. The Body card can contain critical measurements based on the ISO standard (see Figure 31).

![SYMCAD Body Card information based on ISO 8559 (Telmat Industrie, 2000)](image-url)
On the other hand, [TC]\(^2\) provides user customizable measurements in terms of syntax and definition in addition to its original measurement data (See Figure 32). The measurement terms can be fully customized by the user and, in general, measurement definitions are customizable with a focus on the best strategy to fit apparel, rather than anthropometric standards. A MEP (proprietary) file is used for invoking different sets of measurement definitions (Bruner, 2002).

![Figure 32. [TC]\(^2\) User customizable measurements in terms of syntax (Bruner, 2002)](image)

However, most body scan companies do not have an approved body measurement standard for providing a consistent set of body measurement data. Several studies (Brunsman et al, 1997; Simmons, 2001) show that different syntax with semantics of body measurement scan data have been used for developing 3D body scanning systems, and that there are potential problems with inconsistency of measuring techniques.

In a comparison of three-Dimensional Body Scanning and Physical Anthropometric Methods (Simmons, 2001), seventeen measurements were chosen as
being critical to the design of well fitting garments, and on each of the seventeen measurements, the method of data capture was described for three different scanners [TC]², WBX, and SYMCAD. Table 2 shows the result from the study. Each body scanning system had different body measurement terminology.

Table 2. Measurement terms compared to selected scanners (Simmons, 2001)

<table>
<thead>
<tr>
<th>Terms</th>
<th>2T4 (TC)²</th>
<th>WB4 (Cyberware,Inc.)</th>
<th>SYMCAD (Telmat Industrie)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midneck</td>
<td>Collar</td>
<td>Neck Circumference</td>
<td>Neck Girth</td>
</tr>
<tr>
<td>Neckbase</td>
<td>Neck</td>
<td>N/a</td>
<td>Neckbase</td>
</tr>
<tr>
<td>Chest</td>
<td>Chest</td>
<td>N/a</td>
<td>Maximum Chest Girth</td>
</tr>
<tr>
<td>Bust</td>
<td>Bust</td>
<td>Chest Circumference</td>
<td>Chest Girth</td>
</tr>
<tr>
<td>Waist-Natural Indentation</td>
<td>Waist</td>
<td>N/a</td>
<td>Natural Waist Girth</td>
</tr>
<tr>
<td>Waist-Navel</td>
<td>n/a</td>
<td>Waist Circumference</td>
<td>Waist Girth</td>
</tr>
<tr>
<td>Hips</td>
<td>Hips</td>
<td>N/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Seat</td>
<td>Seat</td>
<td>Seat Circumference</td>
<td>Seat Girth</td>
</tr>
<tr>
<td>Sleeve Length</td>
<td>Shirt Sleeve Length</td>
<td>Sleeve Length</td>
<td>Total Arm Length</td>
</tr>
<tr>
<td>Arm Length</td>
<td>n/a</td>
<td>N/a</td>
<td>Arm Length</td>
</tr>
<tr>
<td>Inseam</td>
<td>Inseam</td>
<td>Pant Inseam</td>
<td>Inside Leg Length</td>
</tr>
<tr>
<td>Outseam</td>
<td>Outseam</td>
<td>N/a</td>
<td>Outside Leg Length</td>
</tr>
<tr>
<td>Shoulder Length</td>
<td>Shoulder Length</td>
<td>N/a</td>
<td>Shoulder Length</td>
</tr>
<tr>
<td>Across Chest</td>
<td>Across Chest</td>
<td>N/a</td>
<td>Across Chest</td>
</tr>
<tr>
<td>Across Back</td>
<td>Across Back</td>
<td>N/a</td>
<td>Across Back</td>
</tr>
<tr>
<td>Back of Neck to Waist</td>
<td>Neck to Waist</td>
<td>N/a</td>
<td>(1)Back Neck to Waist (2) Back Neck to Belt</td>
</tr>
<tr>
<td>Rise</td>
<td>Vertical Rise</td>
<td>N/a</td>
<td>Body Rise</td>
</tr>
<tr>
<td>Crotch Length</td>
<td>Crotch Length</td>
<td>N/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Thigh Circumference</td>
<td>Thigh</td>
<td>N/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Bicep Circumference</td>
<td>Bicep</td>
<td>N/a</td>
<td>N/a</td>
</tr>
<tr>
<td>Wrist Circumference</td>
<td>Wrist</td>
<td>N/a</td>
<td>N/a</td>
</tr>
</tbody>
</table>

As shown in Table 2, significant variance exists in semantic with syntax that defines each specific body measurement among the several scanners (Simmons, 2001). There were no standard semantics and syntax among the body scanning companies. The problem exists in the consistency of measuring techniques between scanners.
In another study, the experimental study of determining optimal scanning positions and postures (Brunsman et al., 1997) showed that different defining of a subject posture caused inconsistency of body measurement data. The study was conducted to determine optimal scanning positions for surveying the civilian populations of North America and Europe (Brunsman et al., 1997). They had a list of traditional measures of interest to the automotive and apparel industry obtained from the Society of Automotive Engineers (SAE), D13 Subcommitte, and G 13 Subcommitte in the American Society for Testing and Materials (ASTM). They tested three postures with the Cyberware WB4 scanner. The three postures included standing, standard sitting, and coverage sitting where the subject seated with arms raised. Locations of the four heads in 75 degrees and 105 degrees are labeled zero to three in a counterclockwise manner (see Figure 33).

![Figure 33](image)

**Figure 33.** Scanning three postures and six scan head positions (Brunsman et al., 1997)

Clothing design test mannequins were digitized and the digitized images were segmented to extract surface area information about specific body regions. The scanned
images were divided into eighteen 9 cm segments for the standing postures and twenty 
6.4 cm segments for the standard and coverage sitting postures. The standing posture 
segments started at the neck and continued downward to the ankle. The sitting 
mannequin was segmented in a similar manner, but this mannequin also had a head, 
hands, and feet (Brunsman et al., 1997).

The result was that a scanned surface area was highly dependent on the position 
of the bodies (see Figure 34, 35, and 36). Figures 34, 35, and 36 show the segments 
surface area variation of the standing and sitting posture in all six positions. In the 
Figures (34, 35, and 36), numbers on the x-axis indicate the mannequin surface area 
segments, and numbers on the y-axis show the surface area measurements in six positions 
(H0, H2, H1-2, H3-0, H0-1, and H2-3).

Figure 34. Surface area of standing postures (Brunsman et al., 1997)
Figure 34 shows that traditional standard sitting postures still provided good consistency and measurement capabilities when compared with other postures in Figure 35 and 36 (Brunsman et al., 1997). As shown in Figure 34, there were negligible surface area differences between the scanning positions. For example, there is no shading of body parts in sections 1-2 (neck and shoulder region) of the standing posture. However, in the mid torso region (section 3-7) there is substantial shading between the arms and the side of the torso. As a result, there was increased surface area variation with a lot of missing data in the mid torso region (Brunsman et al., 1997). Figure 35 shows the segments variation in the surface area of standard sitting postures (See Figure 35).

![Graph showing surface area of standard sitting postures](image)

**Figure 35.** Surface area of standard sitting postures (Brunsman et al., 1997)
In the lower torso, lower leg area segment numbers correlated with a scanning head position do not show variations (e.g. segment 11 in x-axis). However, shading causes differences in surface area viewed by the scanner in standard sitting postures. These areas include the mid torso and upper thigh regions for the standing postures in Figure 34, and standard sitting in Figure 35. The coverage sitting posture in Figure 36 had a similar trend, but the shading effect was less drastic (See Figure 36). It is very important to understand that position information is highly dependent on the posture used and the definition of the posture.

Figure 36. Surface area for coverage sitting postures (Brunsman et al., 1997)
Determining Landmarks from Body Scan Data

A landmark is a mark placed on a human body to identify the origin, end-point, or level of a measurement (Clauser et al., 1986). Landmarks are specified as a unique point, and all measurements are taken relative to one or more points on the body (Arlow et al., 2001). Determining landmarks is critically required in any measuring procedure with either a traditional tape measurement method or a body scan method.

According to a study of automated extraction of anthropometric data from 3D images (Paquette et al., 1998), the automated data extraction software existed but pre-marked landmarks to define measurement locations had to be done by a trained anthropometrist. Even though a body scanning system could provide all scanned data from a human body, landmarks were required for developing the body measurement data extraction software. For this reason, several studies on body measurements (Clauser et al., 1988; Hutton et al., 2002; Paquette et al., 1998; Robinette et al., 2002) show that determining landmarks is a very essential procedure for certain systems.

In the U.S. army anthropometric survey 1987-1988 for Measurer’s Hand Book (Clauser et al., 1988), a reference used for the ASTM and ISO body measurement standards, body dimensions were defined in terms of body landmarks to ensure that each body dimension was measured accurately and consistently from subject to subject. In the study, landmarks were categorized with two different types, ‘drawn landmarks’ and ‘undrawn landmarks’.

About sixty five landmarks (designated by lines, crosses, and dots), called as ‘drawn landmarks’, were drawn with reference to underlying bones or muscles in
advance of the measuring. Later, these landmarks were touched by an electronic sensor on the automated headboard to obtain three dimensional data. And thirty easily identified landmarks, called as ‘un-drawn landmarks’, such as “the tip of the thumb”, “bottom of the ear”, or “the lowest point of the elbow bent 90 degrees” were drawn by the markers. It was the responsibility of the measurers to learn the definitions and locations of those thirty ‘un-drawn landmarks’ that pertain to measurements at their stations (Clauser et al., 1988). Table 3 shows the types of landmarks used in the study.

Table 3. Types of landmarks in the Measurer’s Hand Book

<table>
<thead>
<tr>
<th>Types of Landmarks</th>
<th>Detail Landmarks</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawn Landmarks</td>
<td>Acromion/ Anterior superior iliac spine/Biceps point/ Bust point/Calf/Cervicale/Clavicle point/Crinion/ Deltoid point/Dorsal juncture of the foot and leg/ Fifth metatarsophalangeal protrusion/First metatarsophalangeal protrusion/ Gluteal furrow point/Iliocristale/Infraorbitale/Infrathyroid/Inner thigh/Lateral femoral epicondyle, standing and sitting/ Lateral malleolus/Menton/ Metacarpale II/Metacarpale V/ Mid patella/Mid shouderl/ Mid spine/Neck, anterior, right lateral, and left lateral/ Olecranon,center/Radiale/ Scye/Sellion/ Stylion/Submandibular/ Suprapatella/Suprasternale/ Tenth rib/Tragion, right and left/ Trapezius point/ Trochanter/ Trochanterion/ Waist (Natural indentation)/ Waist (Omphalan)Wrist.</td>
<td>Drawn landmarks were located with reference to underlying bones or muscles</td>
</tr>
<tr>
<td>Undrawn Landmarks</td>
<td>Abdominal point/ Acropodion/ Axillary fold/ Buttock point/ Chin/ Dactyion II/ Dactyion III/ Dorsal juncture of the calf and thigh/Ear point, bottom, top/ Ectocanthus/ Elbow crease/ Heel point/ Inferior breast point/ / Medial malleolus Knee point/ Olecranon/ Otobasion superior/ Posterior superior iliac Spine/ Ptetion/ Submandibular/ Thelion/ Thigh point/ Thumbtip/ Top of head</td>
<td>Undrawn landmarks are obvious and easy to locate from subject to subject</td>
</tr>
</tbody>
</table>

As shown in the Table 3, the detail landmarks were listed with anthropometrical terminology. However, most of this terminology is not commonly used in the apparel industry. This limits the use of the measurement terminology and method for apparel applications. The determining landmarks relied on the measurers’ anthropometrical
proficiency with a human body. For example, an abdominal point was defined as the most protruding point of the relaxed abdomen of a seated subject (Clauser et al., 1988). Determining the most protruding point is based on a measurer’s interpretation. As in other traditional manual methods for locating landmarks in the standards (ASTM, 1999; ISO, 1981; ISO, 1989), this has limitations on the description of landmarks for 3D body scanning systems. A measurer’s interpretation with ‘feel’ can not be recognized by 3D body scanning systems.

A study of 3D human modeling (Hutton et al., 2002) shows that the placement of body landmarks was an essential step in processing the image and suggested landmark detection for automatically locating relevant body landmarks. The landmark detection methods were using silhouettes, body graphs, and interpolation (see Figures 37, 38, and 39). Figure 37 shows the silhouette method.

Figure 37. Silhouette detection (Hutton, et al., 2002)
As shown in Figure 37, the front and side silhouettes display useful information for detecting landmarks. The side silhouette provided the prominence of bust, abdomen, seat and back regions. The front silhouette provided additional useful information such as around the waist, shoulders, neck and arms. This method narrowed the search region as much as possible in the study (Hutton et al., 2002). Figure 38 shows body graphs, plots of contour body measurements that provide distinctive profiles that can be used to classify shape and help to identify landmarks such as waist and crotch (see Figure 38).

As shown in Figure 38, a body graph and plots of contour body measurements are used for identifying waist points. This method can be applied to crotch region. The indicated position represents the crotch region by observing the change in cross sectional shape as you move upwards through the crotch region (Hutton et al., 2002). Using silhouette and body graphs, interpolation was suggested for determining landmarks in the study of 3D human modeling (Hutton et al., 2002).
For example, the shape of the body to the front and rear of the crotch was interpolated through the position (see Figure 39). These methods would be useful for determining landmarks from 3D body scan data because landmarks in any body scanning system have to be determined in advance of extracting measurement body scan data, similar to traditional measurement methods. After landmarks are predefined and saved in a body scanning system, then some body scanning systems can provide necessary landmarks automatically (Hutton et al., 2002).

![Figure 39. Crotch region search (Hutton et al., 2002)](image)

Hamamatsu Photonics’ BodyLine scanner provides manual tape measurement functions and automatic measurement functions (Hamamatsu Photonics, 2000). Hamamatsu Photonics’ BodyLine scanner extracts landmarks automatically from the scanned data for use with the electronic tape measure on the screen (Hamamatsu Photonics, 2000; Paquette, 1996), and also it can create a new landmark by putting a
special tape manually on the body in disagreement of automated landmark (see Figure 40).

![Image](image.png)

Figure 40. Hamamatsu photonics landmarking method (Hamamatsu photonics, 2002)

As shown in Figure 40, tapes on the body assign four new additional landmarks that are displayed with green points. The BodyLine scanner updates measurements automatically after adjusting the landmarks interactively. The manual tape measurement functions use a maximum of four landmarks for each measurement. For example, a straight line measures distance between two landmarks, an open curve measures distance passing through 2, 3 or 4 assigned landmarks, and a closed curve measures the length of loop passing through 1, 2, or 3 assigned landmarks. On the other hand, 3D automatic body measurement functions detect automatically 47 landmark points and provide automatically 62 measurements that are related to ISO8559 (see Figure 41 and 42).
Figure 41. Automatic landmark detection from BodyLine Scanner in a front body view (Hamamatsu Photonics, 2003)
Figure 42. Automatic landmark detection from BodyLine Scanner in a back view (Hamamatsu Photonics, 2003)
The basic landmarks are detected from XYZ point clouds. Using landmarks, curved distances between the specified points on the surface of the body can be measured. The automatically provided landmarks from the body scanner could result in more consistent measurements than traditional tape measurements done by hand. However, the pre-defined landmarks are still required and could be different by application. Figure 43 shows sample landmark data from the Hamamatsu Photonics. Points on the figure indicate landmarks automatically, and each landmark location is expressed with the height measurement from the floor to the each indicated point.

**Landmark Height Measurements (mm)**

<table>
<thead>
<tr>
<th>Landmark</th>
<th>Measurement (mm)</th>
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*Figure 43. Landmarks and the height measurements (Hamamatsu Photonics, 2000)*
Cyberware scanners with CyPie software, used in North America and Italy for the Civilian American and European Surface Anthropometry Resource (CAESAR) project, show different pre-defined landmarks. The 3D body scans were interrogated using a semi-automated process to extract the 3D location of seventy-two pre-defined landmarks for two different poses, a sitting pose and a standing pose. The landmarks were marked on the body with stickers for later identification (Robinette et al., 2002). Figure 44 shows an example list of the front upper body landmarks in a visual index.

Figure 44. Front upper body landmarks in CEASER project (Robinette et al., 2002)
In Figure 44, a crotch landmark could not be shown in the visual index. The crotch point was calculated using the crotch height value from the traditional measurements for the vertical value and the midpoint of the two trochanterion landmarks (right and left) for the other two dimensions (Robinette et al., 2002). This shows different methods of determining landmarks in the study of 3D human modeling (Hutton et al., 2002) and the U.S. army anthropometric survey 1987-1988 for Measurer’s Hand Book (Clauser et al., 1988). These references for determining landmarks can be used for training people to get measurements, but there is no accepted standard method for determining landmarks from point cloud in a body scan system.

**Current Data File Formats and XML (eXtensible Markup Language)**

**Current Data File Formats for Describing Body Measurements**

Information on the format of body scan data is very important for determining compatibility between 2D CAD systems and 3D scan systems since most apparel CAD and virtual design suppliers are joining with body scan suppliers to support mass customization with accurate body measurement data. Body scan data includes body measurements and a body image with point cloud. Generally, VRML is a dominant file format for the body image data, and XYZ is a commonly used format for the raw scan data files. However, each body scan supplier has various detail body measurement data file formats for describing body measurements or transferring the data.

In an open discussion at the ASTM D13.66 sub committee’s 3D body scanning task group meeting at the College of Textiles at North Carolina State University in
September, 2002, the body scan data file formats shown in Table 4 were identified by the participant body scan suppliers: [TC]², Hamamatsu Photonics, and Cyberware, Inc..

Table 4. Body scan data formats (Based on information from ASTM D13.66 body scan task group meeting at NC 2002)

<table>
<thead>
<tr>
<th>3D Scan Data Formats</th>
<th>[TC]²</th>
<th>Hamamatsu Photonics</th>
<th>Cyberware, Inc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Point Cloud Data (millimeter units base)</td>
<td>*.bin (Microsoft Binary Format)</td>
<td>Point Cloud Input: *.abl (C9036 unique format) Output: VRML2.0</td>
<td>Point cloud, Tessellated Points</td>
</tr>
<tr>
<td></td>
<td>*.wrl (VRML 2.0 3D data standard)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measurements, Shape Parameters</td>
<td>*.ord (ASCII list, Gerber list), measure name=value *.xls (Microsoft Excel), batch output list Surface Landmarks, Internal Joints, landmarks, joints (ASCII list name,X,Y,Z)</td>
<td>Measurement data output format : ASCII(txt) file</td>
<td>N/A</td>
</tr>
<tr>
<td>Measurement Definitions</td>
<td>*.mep (proprietary), for invoking different sets of measurement definitions</td>
<td>ISO8559</td>
<td>N/A</td>
</tr>
</tbody>
</table>

As shown in Table 4, [TC]² provides data file formats for point cloud, body surface model, and extracted measurements that are found in data flow from 3D scan to 2D pattern. The extracted body measurement data, one subset of the body scan data, is
very important for pattern alteration, outputting pattern outlines, and draping garments for visualization. At this point, measurement definitions and standards are demanded by body scan users, and the definitions in $[TC]^2$ are fully customizable within the measurement definition data file (*.mep) format.

The customizable measurement definitions include measurement units, terminology, and methods. In general, measurement definitions are customizable with a focus on the best strategy to fit apparel, rather than anthropometric standards. According to Dr. Bruner (2002) during the 3D body scan seminar, sample definition sets have been developed for many ISO measurements and for the draft eT-Cluster (European Standard) with an *.mep data file format. In addition, $[TC]^2$ was developing a generic *.dxf format for direct pattern output from body scans.

As shown in Table 4, Hamamatsu Photonics also provides a variety of data file formats including point cloud, body surface model, and measurement data, but each body scan data file format is different from those of other body scan suppliers. For example, one type of output data file format, VRML, is commonly used to display the body surface, but point cloud data and others are unique in their data file format. The measurement data file format was an ASCII file or *.txt file, and the file format is compatible with $[TC]^2$’s measurement data file format. However, there was no evidence of successful transfer of data between $[TC]^2$ and Hamamatsu Photonics’ scanners. Definition of body measurements is still required.

As shown in Table 4, Cyberware, Inc. has a body scan data file format to display the body surface. Body scanners from the Cyberware, Inc. were used in Civilian
American and European Surface Anthropometry Resource (CAESAR) project, and the PLY file format was used to deliver body measurement data in the CAESAR project. However, the body measurement data file format is different according to each organization or researcher. For example, the LPD file format (Hutton et al., 2002) was used for the UK sizing survey, and later the XML (eXtensible Markup Language) format was used in European commission standardization project (eT-Cluster) for the integration of 3D body measurement, advanced CAD, and personalized avatars in the European fashion industry.

**Current Standard Data File Formats for Pattern Data Exchange**

In the apparel industry, CAD/CAM data compatibility and standard data file formats have been critical issues as more companies increase globalization and partnerships with new technology suppliers such as 3D body scan suppliers. Apparel CAD suppliers have encouraged the industry to establish standards for presenting CAD/CAM data in formats that would allow apparel and sewn product producers to utilize a choice of machinery and software from different vendors, and to exchange information with contractors or third parties that may not have the same machinery and software.

According to Richard Downhan, customer support manager for Assyst-Bullmer, different systems between contractors and customers cause time consumption when the contractor might be forced to re-digitize pattern pieces, purchase compatible systems, or establish a customized interface to get the data into its systems. At the same time, producers currently are limited in their ability to switch contracting partners if their

According to Chang (Chang, 2000), prior to the ASTM D13.66, the ANSI/AAMA 292 pattern data interchange (or ANSI/AAMA 292 DXF) standard was available for the CAD/CAM vendors. First approved by ANSI/AAMA in September 1993, 292 DXF was a good first attempt to define a standard. The standard was based on Autodesk Inc.’s DXF file format, which is designed to exchange mechanical engineering drawings (Chang, 2000). DXF is a specially formatted ASCII file, which means it is created using standard characters on the computer keyboard and can be viewed in a word processing application like Microsoft Word (see Figure 45.)
As shown in Figure 45, ANSI/AAMA 292 DXF includes a set of conventions that represent apparel piece geometry, or 2-D flat patterns, and associate meanings to pieces, base size name, lines, and points. The standard defines how the conventions should be organized in a file for exchange of information between CAD systems. For example, there are 14 layers for organizing the data that are divided into fourteen categories when written into the ASCII DXF file format. Thus, the DXF translation programs know where to go within the file to get the information needed to display and work with the pattern piece. The 292 DXF standard’s development received good participation from industry CAD/CAM vendors, and it was relatively easy to implement (Chang, 2000).

However, ANSI/AAMA 292 DXF documentation is not very clear in its definitions and the standard does not include a grade rule growth specification or curve-
smoothing algorithms leaving an empty space for different CAD vendors to have different interpretations of the curve line control. For example, one system may require the curve line to pass through control points, whereas a different system may only require the same curve line to pass along the points. This difference in curve-smoothing algorithms can cause accuracy problems when pattern pieces are imported. In addition, the DXF structure limits the amount of information (Chang, 2000). This results in confusion and inconsistent implementation by apparel CAD/CAM vendors. Currently, ASTM D13.66 has been developing a new standard for pattern data exchange, and XML has been discussed for the future data file format.

**Potential Use of XML (eXtensible Markup Language) for Standardization**

XML (eXtensible Markup Language) is a potential data file format for the modeling, developing and prototyping of communication standards and interfaces for the following reasons: extensibility, structure, mega data transport and easy conversion. The advantages of XML are being touted by many branches of the sewn products industry and beyond for use in software development, web development, collaborative communications and supply chain management (Chang, 2000). XML allows for transaction and catalog information to be exchanged via internet-based networks; web-based collaborative planning, forecasting and replenishment (CPFR); and business-to-business (B2B) exchanges (Eshelman, 2000). With its almost infinite flexibility and user-friendly attributes, XML also is attractive from a standards development viewpoint (Chang, 2000).
According to Peck (2000), standards based upon XML will be developed for communication interfaces in a supply chain consisting of links that receive products from many suppliers in the chain and create products for many customers in the chain. As a result, linear relationships of suppliers, manufacturers and customers (supply chains) will be represented. XML has already been implemented in apparel companies which are dealing with e-business, globalization, and standardization.

For example, the implementation of XML is found at InfoMat.com, the premier online information source for the apparel and textile industry. InfoMat.com has a partnership with Liquidity Service Inc. who has XML formats of surplus listings that are available to global network partners in apparel, construction, and consumer goods. InfoMat.com offers surplus apparel merchandise to their users by using the auction listings with Liquidation.com's DTD (Document Type Definition). The XML format enables websites and portals to easily integrate the listings into their existing infrastructure (Liquidity Services, Inc., 2003). This case might be applicable to many apparel manufacturers who deal with several different retailers, and each with their own unique methods of communicating.

In another example, the specific use of XML for standardization is found in the global standard organization for apparel business. About 90% of US apparel companies use subsets of ANSI (American National Standards Institute) ASC X12 EDI (Electronic Data Interchange) standards to communicate with their suppliers and customers (Baker, 2002). These ASC X12 standards are recognized by the United Nations as the standard
for North America. In Europe, however, apparel companies are using EDIFACT messaging languages and systems to communicate (Baker, 2002).

According to Baker, when companies expand globally through acquisition or business relationships a sudden merge of two sets of unrelated electronic communications means huge financial and time losses. Through XML, an emerging B2B commerce computer language, EAN and UCC, two non-profit global standards organizations, have been enabling companies to define standards, and resolve specific business issues (Baker, 2002).

Since XML has a potential for standardization in most areas of the industry, the opportunities for use of XML were discussed at the July 2000 meeting of ASTM D13.66 sub committee, which is the CAD/CAM pattern data exchange standards task force group of ASTM (American Society for Testing and Materials). According to Chang, XML is an exciting emerging technology with great potential, is a universal format for exchanging information between software components, and is legible to both computers and human beings (Chang, 2000).

**Summary of Literature Review**

From the literature review, it was clear that there was a lack of consensus on terminology and acceptance of standard measurements for apparel. Each body scanning system has its own methods of data acquisition, extraction, and output. Even though some of these systems have measurement extraction software to interpret the final body measurement data, the definitions of the body measurements, and landmarks were different.
There was no approved standard for body measurement methods and determining landmarks for body scanning systems. There was no approved standard format for transmissions of body scan data between body scanning companies and CAD companies. Critical body measurements required in the apparel industry are different from the measurements offered by many body scan companies. Even current standards were poorly defined in some respects and lacked meaningful definitions for many pattern data processes, properties and attributes.

Therefore, a set of standards is needed to integrate the processes of 3D body scanning and CAD systems. In addition, a set of standards for body measurement terminology and methodology with the integration process is very important for customization in the apparel industry since it will assist in fitting of the final garment.
CHAPTER III

METHODOLOGY

Research Objectives

The objective of this research was to develop a data file format model for bi-directional exchange and interpretation of body measurement data generated by optical 3D body scanning systems and apparel CAD systems. This research has led to the development of standardization of the body measurement terminology. A software program with the data file format has been developed to activate the connectivity between the CAD system and the 3D body scanning system to exchange body measurement data for pattern design or alteration.

Specific research objectives included:

Objective 1: To investigate the potential for connectivity of scanning systems with apparel CAD systems by comparison of the specifications of each body scanning system.

Objective 2: To uncover inconsistencies and potential problems in existing standards of the body measurement terminology and methods for apparel applications.

Objective 3: To develop a set of Identification Codes that were used to represent specific body measurements, providing semantics (meaning of each code) and syntax (rules of the code arrangement) for both 3D body scanning systems and apparel CAD systems. The MMP (Metaphor Matching Process) model was designed for developing the set of Identification Codes with syntax in this dissertation.
Objective 4: To develop an exchange data file format for achieving standardization of the body measurement terminology for bi-directional interpretation and transmission of data generated by 3D body scanning systems and 2D CAD pattern generation systems. This was presented in XML (eXtensible Markup Language) format in this dissertation. Validation will be accomplished by format data exchange testing with Gerber Technology, Inc. and [TC]2.

Objective 5: To provide a logical IDEF1X model of data flow structure to demonstrate the connectivity between 3D body scanning system and CAD system in apparel design.

**Research Method**

To approach Objective 1, to research the potential for connectivity of scanning systems with apparel CAD systems, existing body scanning companies were investigated between December 1999 and December 2000. The companies were Cyberware Inc., [TC]2, Telmat industrie, Wicks and Wilson Ltd, Hamamatsu Photonics, Vitronic GmbH, tecmath AG (Human Solutions GmbH), 3D Scanners, Hamano Engineering Co. Ltd., Puls Scanning system GmbH, LASS (Loughborough Anthropometric Shadow Scanner), Cognitens Ltd., Carl Zeiss Inc., Faro Technologies Inc., CAD modeling Inc., and Polhemus CSC Provider.

Each company was surveyed to gather information related to system capabilities, and the specifications of each body scanning system including: the scanning time, volume of the scanner booth, vision device, and the required system environments, the computer operating system, the software, the hardware, and data formats.

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To approach Objective 2, to uncover inconsistencies and potential problems with body measurement standards terminology and measurement methods used for apparel applications, standards for apparel sizing were collected from ASTM D 5219 and ISO 8559. These standards have been used for developing the 3D body scanners by Hamamatsu Photonics and Telmat industrie. The standards were compared with current technical references that are used in apparel design and manufacturing.

To approach Objectives 3, 4 and 5, a software program (XML and Database) was developed for achieving standardization of the body measurement terminology for bidirectional interpretation and transmission of data between 3D body scan systems and CAD systems. To develop XML schema (XSD), the following procedural steps were required:

- Set of Identification Codes
- Metaphor Matching Process
- Interpretation and transmission of body measurement data
- Data structure to demonstrate the connectivity

**Procedures**

**Set of Identification Codes**

**Approaches:**

- To develop Identification Codes of body measurements

To develop a set of Identification Codes, the following procedure was necessary (See Figure 46).
Figure 46. Set of Identification Codes

1. Store all body measurement terminology used in anthropometry, ISO, and ASTM in a database system.

2. Determine minimum number of landmarks on the body or body-surface scan features by analyzing critical body measurements for apparel applications: Landmarks were selected from ISO 8559 and ASTM D 5219-99. The landmarks are used to identify the origin, the starting point, or the end point of a given measurement.

3. Create Identification Codes for each semantic (meaning of each body part)

4. Develop syntax (a rule) that can describe each body measurement.
5. Provide semantics and syntax for body scan data and apparel CAD: Semantics represent meanings in relation to existing body measurement terminology and symbolic logic codes with syntax, which is a pattern of formation of the meaning.

6. Provide a set of Identification Codes.

   The Identification Codes were examined to see if they matched with current body measurements in ISO and ASTM using the Metaphor Matching Process (MMP). The MMP creates bi-directional flow of body measurement data as garment patterns are developed or altered.

**Metaphor Matching Process**

<table>
<thead>
<tr>
<th>Approaches:</th>
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<tbody>
<tr>
<td>• To create a unique Metaphor Matching Process (MMP) based on Knowledge Management (KM) concept to transfer tacit knowledge of measurement terminology and method to simplify explicit knowledge.</td>
</tr>
<tr>
<td>• To create bi-directional flow of data as garment patterns are developed or altered using body measurement data.</td>
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The Metaphor Matching Process (MMP) was developed for making a consensus idea of same object that could be expressed in many ways. The MMP was based on the Knowledge Management (KM) concept of transferring tacit knowledge to simplify explicit knowledge, and based on Lofting’s mathematical approach (Lofting, 1992). Lofting’s approach was one of the methods for mapping analogy and metaphor (Lofting, 1992).
The database that contained all body measurement data using the standard set of Identification Codes from the previous procedure was used for bi-directional interpretation and transmission of data generated by 3D body scanning systems and 2D CAD pattern generation systems (See Figure 47 and Figure 48).

**Figure 47.** Metaphor Matching Process

**Figure 48.** A front view of 3D body scan picture with a code and a pattern
Interpretation and Transmission of Body Measurement Data

Approaches:
- To develop a data file format model with XML (eXtensible Markup Language) for interpretation and bi-directional transmission of critical measurements from a body scanning system to a CAD system.

A database was developed containing body measurement data, and using the standard set of Identification Codes developed for apparel uses. A measurement data set in XML (eXtensible Markup Language) was developed for interpretation and bi-directional transmission of critical measurements from a body scanning system to a CAD system, including XSD (XML Schema Definition Language) for validating the XML document (See Figure 49).

![Diagram](image)

**Figure 49.** A draft of the standardization software program

XMLSPY5 software was used for evaluating formation and validation of the program designed for this Objective 4. The developed XML format was sent to two
sample companies [TC]² and Gerber Technology, Inc. to determine if it would be a viable standard format for body measurement data connectivity to CAD.

**Data Structure to Demonstrate the Connectivity**

<table>
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<tr>
<th>Approaches:</th>
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</thead>
<tbody>
<tr>
<td>• To support structure of the standardization and integration for the apparel application domain by providing Integration Definition for Information Modeling (IDEF1X).</td>
</tr>
</tbody>
</table>

The Integration Definition for Information Modeling (IDEF1X) method was used to demonstrate the connectivity of body measurement information between apparel CAD data and body scan data. IDEF1X is one of methods of Integrated Computer Aided Manufacturing Definition (IDEF) that includes IDEF0 (Function model) and IDEF2 (Dynamics model). In this study, IDEF1X was chosen for the semantic data models with reason that IDEF1X was used to produce an information model which represents the structure and semantics of information within the environment or system (Federal Information Processing Standards Publication 184, 1993). IDEF1X has been used to model a wide variety of automated and non-automated systems (Young, 2000).

The IDEF1X supported structure of the standardization and integration for the apparel application domain described in Objective 5 is based on the following measurement data flow (See Figure 50).
Instrument and Resources

ASTM, ISO 8559, technical references for apparel manufacturers, and
anthropometry were collected for the references of the body measurements. Access
Database with SQL was used for data storage and as a development standardization tool.
XML notepad and XMLSPY5 were used for formatting the measurement data sets.
CHAPTER IV

RESULTS AND DISCUSSIONS IN OBJECTIVE 1: INVESTIGATION OF POTENTIAL USE OF BODY SCANNING SYSTEMS IN THE APPAREL INDUSTRY

The research outlined in Objective 1 has been published in the Journal of Fashion Marketing and Management (“3D body scanning systems with application to the apparel industry”, Journal of Fashion Marketing and Management, vol.5, no.2. 2001). The research surveyed existing body scanning systems to assess connectivity with apparel CAD systems, and to investigate potential use of 3D body scanning systems in the apparel industry.

Since the publication of this paper there has been one new scanner to enter the market. The system, ‘Intellifit’, has been discussed in the literature review and is similar to the existing body scanning systems surveyed in terms of connectivity to apparel CAD systems.

<Inserted the paper as published.>
3D body scanning systems with application to the apparel industry

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Abstract
The ability to customise garments for fit is directly tied to the availability of a comprehensive, accurate set of measurements. To obtain accurate physical measurements, a basic knowledge and set of skills are required that are not often found in the average salesperson at a retail clothing outlet. The development of three-dimensional body-scanning technologies may have significant potential for use in the apparel industry, particularly for customisation or mass customisation strategies to be employed. The purpose of this study was to review all the 3D body scanning systems currently available and to determine the underlying principles that allow these systems to work. Specifications of each system were compared in order to provide some direction for further research into the integration of these systems with current apparel CAD pattern design or pattern generation technologies.

Introduction
In the apparel industry, the ability to customise garments for fit is directly tied to the availability of a comprehensive, accurate set of measurements for each interested consumer. Regardless of whether one might perceive ‘fit’ to be good or bad, it is impossible to approach the consumer’s perceptions of good fit without a set of accurate measurements in the beginning. To obtain accurate physical measurements, a basic knowledge and set of skills are required that are not often found in the average salesperson at a retail clothing outlet. In addition, most consumers are unwilling to take time to be measured or subject themselves to the intrusion. A 1988 anthropometric survey of US Army personnel required four hours physically to landmark, measure and record the data of one subject (Paquette, 1996). How many consumers would be willing to go through something similar?

The development of three-dimensional bodyscanning technologies may have significant potential for use in the apparel industry, for a number of reasons. First, this
technology has the potential for obtaining an unlimited number of linear and non-linear measurements of human bodies (in addition to other objects) in a matter of seconds. Because an image of the body is captured during the scanning process, the location and description of the measurements can be altered as needed in mere seconds. Secondly, the measurements obtained using this technology have the potential to be more precise and reproducible than measurements obtained through the physical measurement process. Thirdly, with the availability of an infinite number of linear and non-linear measurements, it is possible for garments to be created that mould to the three-dimensional shapes of unique human bodies. Fourthly, the scanning technology allows measurements to be obtained in a digital format that could integrate automatically into apparel CAD systems without the human intervention that takes additional time and can introduce error. Ultimately, 3D body scanning technologies may enable the industry to produce mass customised garments.

This study reviewed all the current 3D body scanning systems and seeks to determine the underlying principles that allow them to work. Specifications of each system were compared in order to point the way to further research into the integration of these systems with current apparel CAD technology.

3D Body Scanning Systems

In the majority of cases, three-dimensional body scanners capture the outside surface of the human body by using optical techniques, in combination with light sensitive devices, without physical contact with the body. The scan subject usually wears form-fitting briefs or bicycle/running shorts during the process. Body scanning systems consist of one or more light sources, one or more vision or capturing devices, software, computer systems and monitor screens in order to visualise the data capture process. The primary types of body scanning systems are laser and light. Other systems also exist, but are not currently used for capturing the shape of human bodies. Table 1 lists scanners by the type of technology used to capture the image. Three-dimensional scanning systems can be found in a variety of areas such as statistical analysis, modelling, animation, medicine, anthropometry and apparel. Leading systems can be found in Japan, the United Kingdom, Germany, France and the United States.

One of the earliest 3D body scanning systems was a shadow scanning method developed by Loughborough University in the UK. Original shadow scanning methods differ from other conventional structured lighting approaches in that they require very little hardware besides a camera, a desk-lamp, a pencil and a checkerboard. The camera faces the scene, illuminated by a halogen desk lamp. The camera captures images as an operator moves the light so that the shadow scans the entire scene. This constitutes the input data to the 3D reconstruction system (Bouguet and Perona, 2000).

The Loughborough Anthropometric Shadow Scanner is an automated, computerised 3D measurement system based on triangulation. The subject stands on a rotating platform and is turned 360 degrees in measured angular increments. A slit of light is projected onto the body in a vertical plane that passes through the centre of the rotation. A column of cameras is used to read the image of projected light. From the camera image of the edge of the light slit, the height \( h \) and horizontal radii \( r \) of the body at the vertical plane can be easily calculated. The measured data are 3D surface coordinates of a body in cylinder coordinate form. The resolution of measurements in the vertical and the radial directions are 1 mm and 1.6 mm respectively, according to the camera resolution (Jones et al, 1995).

Telmat

SYMCA D Turbo Flash/3D is Telmat’s 3D body scanning system, developed in the framework of a partnership with the French
Navy (Soir, 1999). The system has a size selection table based on ISO 8559 and the coordination of integrated garment ensembles or packages. The resulting measurement data can be integrated into apparel CAD systems such as Gerber Technology’s Accumark system or Lectra System’s Modaris software.

Telmat acquires pieces of information in \( \frac{1}{25} \) of a second. It takes 30 seconds for the cameras to move along the beams and acquire data from the whole body. After computational calculations are made on the formed scanned image, the system is able to generate 70 precise body measurements. It takes less than 15 seconds for the system to extract this data. Among the data recorded are traditional measurements used by clothing professionals, such as neck, waist, chest, bust and hip circumferences. Telmat has demonstrated how measurements could be stored and delivered to the ultimate user with their SYMCAD Body Card. This card has the ability to store all individual body measurements captured using the system.

### White light scanning systems

**Textile clothing technology corporation (TC2)**

The Textile Clothing Technology Corporation (TC2) uses a phase measuring profilometry (PMP) technique that they developed for commercialisation. PMP is similar to Moiré light projection techniques, but differs from Moiré data-capture approaches in that it employs a phase-stepping technique. This method is thought to improve overall image resolution (Paquette, 1996).

The PMP technique uses a white light source to project a contour pattern on the surface of an object. A coupled charged device (CCD) camera linked to a computer detects the resulting deformed light strip. The superimposed projection grating lines interact with a reference grating, forming the fringes. As irregularities in the shape of the target object distort the projected grating, fringe patterns result. The PMP method involves shifting the grating preset

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**Table 1 3D scanning systems by type**

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

* = The Loughborough Anthropometric Shadow Scanner

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distances in the direction of the varying phase and capturing images at each position. A total of four images are taken for each sensor, each with the same amount of phase shift of the projected sinusoidal patterns. Using the four captured images, the phase of each pixel can be determined. The phase is then used to calculate the three-dimensional data points.

The intermediate output of the PMP process is a data cloud of points for each of the six views (right front, left front, and rear in both the upper and lower part of the body). The individual views are combined by the exact orientation of each view with respect to one another. Scanning a calibration object of known size and orientation is an essential step in deriving this orientation. This is known as system calibration (TC2, 2000). The points that result from the data set are the raw calculated points without any smoothing or other post-processing. In order for measurements to be extracted, the data must be further processed by filtering, smoothing, filling and compressing. The PMP method enables faster data acquisition than laser scanning or shadow scanning, but is unable to provide colour information.

Wicks and Wilson, Limited

Triform is a non-contact 3D image capture system from Wicks and Wilson Limited in the United Kingdom. White light (in the form of a halogen bulb) and a variation of the Moiré fringe technique are used to capture the 3D shape of an object. The 3D shape is a coloured point cloud on the monitor screen that looks similar to a photograph of the subject.

Triform has already been tested in a large garment sizing survey in the UK organised for Marks and Spencer. They anticipate that it will increase sales, enable virtual displays at point of sale and in catalogues, and can provide a wider range of garments than a normal storeroom. Virtual garment try-on will also be possible in the future. This technology is expected to have application in e-commerce for Internet shopping, in the medical field to assist surgeons in case management and planning, in multimedia and image manipulation, and in garment sizing for the apparel industry.

Light emitting diodes (LED)

Hamamatsu

The Hamamatsu Body Lines (BL) scanning system uses near infrared LED (light emitting diodes) to obtain scan data. The system was developed to extract three-dimensional body data using fewer body landmarks and having less missing data than other previously developed systems. Light is pulsed through a projection lens onto the subject. Near infrared light is reflected from the subject being scanned and is collected by the detector lens. The detector lens is a combination of spherical and cylindrical lenses that generate a slit beam on the position sensitive detectors (PSD). According to Kaufmann (1997), the lateral-effect photodiode, also known as a position-sensitive detector (PSD), is used to determine the position of the centroid. Two PSDs are used to compensate for shadowing of one of the detectors. Measurements are extracted from the 3D point clouds for a specified set of measurements. Size selection tables have been developed based on ISO 8559.

Hamamatsu developed the BL scanner for women’s upper torso and tight undergarments. According to Mr Mario Maldari, President of Hamamatsu, USA, the company has been supporting schools in the USA, UK, Germany and Japan to aid in the development of their body scanning system. They have also worked with the Natick Soldier Center to compare their Body Lines system with the Cyberware system used at Natick.

According to a study comparing the Hamamatsu BL scanner and the Natick Cyberware Scanner (Paquette et al., 1998), the Cyberware Natick scan system generally results in measurement values less than those obtained with traditional anthropometry (TA). The Hamamatsu BL scanning system, however, tends to produce either similar or larger circumference
measurements than those observed for TA. The software performed best on chest and hip circumference but it still has difficulty with neck circumferences. Considering measurement variability, the results of the study indicate that the Hamamatsu BL system tends to produce the widest dispersion of measurement values.

**Laser-based systems**

**Cyberware**

Laser scanning methods are used in the Cyberware WB4, WBX, ARN Scan, Fast Scan and Vitus systems. The scanner projects a line of laser light around the body. The laser line is reflected into cameras located in each of the scan heads. Data is obtained using a triangulation method in which a strip of light is emitted from laser diodes onto the surface of the scanned object, and then viewed simultaneously from two locations using an arrangement of mirrors. Viewed from an angle, the laser stripe appears deformed by the object’s shape. CCD sensors record the deformations and create a digitised image of the subject. The cameras positioned within each of the four scanning heads record this surface information when the heads move vertically along the length of the scanning volume. The separate data files from each scanning head are combined in the software to produce a complete integrated image of the scanned object (Paquette, 1996). Unlike other scanning system methods, the laser scanner generates RGB colour values, a process of identifying colour-coded landmarks for data extraction after scanning.

The US Army Natick RD & E Center uses the Cyberware system to develop and analyse body shapes for armour coverage and for other military uniform clothing. The ARN-SCAN, also called Natick-SCAN (NS), was created using toolkits developed by Cyberware.

The WB4 system is controlled by Cyberware’s Cyscan software which performs basic graphic displays. The software is written in C++ and Tcl/Tk. The scan data is convertible to VRML for web-based applications (Cyberware, 2000). It was designed and manufactured as a portable tool for highly versatile and accurate scientific applications and has proved to be invaluable in collecting the data necessary to develop the measurement extraction capabilities required for accurate recruit sizing. However, the scanner has expensive features not necessarily needed on the recruit issue line and requires skilled personnel for its setup and operation. For this reason, Cyberware developed the WBX version of the scanner in 2000.

The WBX version of the scanner collects all of the data required for clothing measurement extraction with a substantial reduction in complexity, size and cost. The WBX system reduces 50 per cent of the cycle time from 40 seconds to 20 seconds. It also reduced the cost by 57 per cent, from $350,000 to $150,000 (ARN, 2000). It has a simpler assembly and operation than the WB4 system and includes a task optimised motion system. The WBX was tested at the Marine Corps Recruit Depot in San Diego during February 2000.

Both scanners are non-contact optical laser scanning systems. Cyberware manufactures and develops 3D body scanning systems for the apparel industry, garment designers, anthropologists, automotive designers, furniture designers, computer game developers and medical applications.

**TecMath**

TecMath is a German company that does consulting in ergonomic product design, vehicle design, work place design, anthropometric databases and statistical analysis. It also supports clothing and shoe design, made-to-measure and ergonomic anthropoids. The company develops software and hardware related to ergonomics and garment measuring systems in its division of human modelling. This company developed the RAMSIS, Contour, Move and Vitus systems.

The RAMSIS system is directed at virtual product design and ergonomic analysis. It was developed in response to the German
automotive industry and is now used by 60 per cent of the automotive industry worldwide. The system is integrated with CAD systems such as CATIA, IDEAS and has applications for anthropometric databases, posture and movement prediction, interior design package and seat design, workplace design and medical design as they relate to ergonomic analysis. RAMSIS is TecMath’s ergonomic tool that takes only 1.3 seconds to scan an object. Contour and Vitus are TecMath’s measurement tools. Move is an optical infrared marker system with automatic tracking of movement.

Contour has been used to develop fit of army clothing and to select sizes from tables which contain basic body dimensions for companies, such as KAKA, DoB and Bundeswehr (TecMath, 2000). Contour is a camera-based measuring system that calculates body dimensions at a relatively low price and in less than two minutes. It automatically classifies clothing sizes and interfaces with pattern design systems, such as Gerber Technology and GRAFIS. The Contour system consists of lightning tubes, a calibration plate, a CCD camera and a frame grabber. It operates on a Windows 95 platform and a standard PC.

Hamano

VOXELAN is Hamano’s non-contact, optical 3D scanning system that scans the body with a safe laser. It was originally developed by NKK in Japan and later taken over by Hamano Engineering Co. Ltd in 1990. The VOXELAN has been used for various purposes, in addition to measurement of the whole human body. The VOXELAN: HEV-1800HSW is used for whole body measurement, the VOXELAN: HEC-300DS is for face detail, and wrinkles are measured with the VOXELAN: HEV-50S. They provide very precise information in a range of resolutions from 0.8 mm for the whole body to 0.02 mm for wrinkles.

Luminance data is obtained from the measured shape data with exact one-to-one correspondence. Measurement points can be defined on the image displayed on the screen. Plaster figures are generated from the measured shape data as cyber space representations. An object is measured from the combination of the front and back data. A birds-eye view of a wired form of the object can also be obtained. Multiple sections can be represented on the same coordinates. The perimeter and area of a cross section of an object can be measured, as well as a diameter across its sides and a diameter across its front and back. The measurements of a longitudinal section can be obtained in the same manner as the measurements of a cross (horizontal) section. From the measurements, solid shapes of the objects are mapped with the colours corresponding to heights varying from the reference position. Moreover, contour mapping is superimposed on them by using a Moiré display function. VOXELAN software operates in a Windows 95 or NT platform and has DXF and IGES data formats, which are used in most CAD systems.

Vitronic

Vitus is Vitronic’s three-dimensional optical scanning system that also automatically calculates body dimensions. The measurement method used is optical triangulation with laser, using an eye safe laser (class 1) and CCD cameras, travelling vertically. It has an automatic calibration facility and an option for colour texture. Vitronic has developed its own software for visualisation and manipulation of 3D scans. It allows visualisation of up to 16 million triangles and 3D points, processing of textures, and data export in various formats, such as VRML and JPG. It is a fast and precise measurement system that interfaces with CAD systems for clothing design.

Other systems

The systems mentioned above are well-known 3D body scanners developed to extract measurement and image data from
the human body. Other 3D scanning systems have also been developed which may have application for the apparel industry, although this is currently indirect. For example, Polhemus developed FastScan to aid in the movement of objects. The resulting point cloud and virtual image data files can be integrated into many CAD systems used in industrial design. 3D Scanners in London has developed products for modelling objects. Their products, Model Maker and Reverse, are well known for measuring and modelling in the automobile industry. Other scanning systems include CogniTens Optigo 100 and Turing 3D. Currently, neither application is used in the apparel industry, though both have unique data extraction software.

Other methods may also be applied to scan three-dimensional objects. A company called Immersion developed a line of MicroScribe scanners that trace the surface of an object. These have not been used to extract measurement data, but have been used in modelling. Carl Zeiss and Faro Technologies also have similar modelling systems. While these systems currently appear to have little application in the apparel industry, it remains to be seen how they may be used as virtual enterprises develop and e-commerce grows.

Advantages of body scanning systems

Compared to traditional measurement methods using measuring tapes and callipers, laser scanning systems have the advantage of speed. For example, the ARN Scan takes 17 seconds in the initial scanning phase and results in a digitised cloud of 300,000 data points to map the body surface. Within 30 seconds, the ARN Scan software extracts accurate measurements from the data cloud (Morton, 1999). Another advantage of 3D body scanning beyond speed is the accuracy and reproducibility of the data, as well as the availability of new or revised measurement extraction at any time.

After the scanning process, the ARN Scan system automatically selects the correct size for the recruit, or indicates the need for a made-to-measure garment if the body is outside the standardised sizing tables. ARN implemented this system for the military at the Marine Corps Recruit Depot at San Diego, California (Morton, 1999). Most recruits’ body shapes change drastically because of diet and exercise during their training and the scanning system makes it possible to find quickly the correct size for their changing shapes.

The disadvantages of 3D scanning technology, compared to traditional anthropometry or tape measurement methods, are the costs of the technology and the problem with missing data because of shading. The armpits and crotch areas are often shaded (Daanen and Jeroen, 1998). Other problems are related to light absorption by the hair and skin colour, movement artefacts and data processing handling.

A comparison of scanner specifications

Scanning time

Rapid scanning time is one of the remarkable advantages for most 3D body scanning systems over the traditional tape measurement method. Speed is important in the reduction of human body movement artefacts and enables the extraction of precious data from many people in a very short period of time.

As shown in Table 2, scanning and data extraction time varies between laser and light scanning systems. Light projection systems are usually faster than laser scanning systems during the scanning sequence of an object; however, the measurement extraction time for several is longer than that of most laser scanning systems. It appears that light scanners generally need more time to calibrate and compute when processing data.

Physical dimensions of scanning systems

The size of each scanner booth varies significantly from one product to the next.
This is a fairly important consideration to the apparel industry since the anticipated placement of these systems will be in retail establishments where floor space is extremely valuable. Table 3 compares each system by booth size, scanned volume and data file size. File size becomes an important issue to consider when evaluating data management, storage, transmittal and use. As e-commerce capabilities develop and intensify, smaller, more manageable files will be essential.

Table 2 Comparison of scanning time

| Light Projection Systems | | |
|--------------------------|------------------|------------------|------------------|
| System                   | Scan time | Process and extraction time | Total |
| TC2—3T6 system           | 10 sec     | 30 sec              | 40 sec           |
| TC2—2T4 system           | 10 sec     | 30 sec              | 40 sec           |
| Hamamatsu – BL           | 7 sec      | 40 sec              | 47 sec           |
| Telmat—SYMCGAD           | 7.2 sec    | 15 sec              | 22.2 sec         |
| Wicks & Wilson—TriForm   | 16 sec     | 60 sec              | 76 sec           |
| Wicks & Wilson—TriForm Body Scan | 16 sec | 4 min | 256 sec |
| CogniTens—Optigo 100     | 6 sec      | 14 sec              | 20 sec           |

| Laser Projection Systems | | |
|--------------------------|------------------|------------------|------------------|
| System                   | Scan time | Process and extraction time | Total |
| Cyberware—WB4            | 17 sec     | 30 sec              | 47 sec           |
| Cyberware—WBX            | 17 sec     | 30 sec              | 47 sec           |
| Vitronic—Vitus Smart     | 10 sec     | 30 sec              | 40 sec           |
| TecMath—RAMSIS           | 1.3 sec    | ?                  | ?               |
| Hamano—VOXELAP           | 4 sec      | ?                  | ?               |
| Polhemus—Fastscan        | 30 sec     | ?                  | ?               |

Table 3 Comparison by booth size, volume and data size

| 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 | 6Mb |
| TC2—2T4 system           | 1.2 × 6.3 × 2.4 | 1.1 × 2.1 | 4Mb |
| TC2—2T4s system          | 1.2 × 4.2 × 2.4 | 1.1 × 2.1 | 4Mb |
| Hamamatsu – BL           | 1.59 × 1.67 × 2.75 | 0.89 × 0.5 | 2 | 0.3Mb |
| Telmat—SYMCGAD           | 3.0 × 1.5 × 2.4 | 0.8 × 1.3 × 2.2 | 10Mb |
| 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 | 3Mb |
| TecMath—RAMSIS           | 2.0 × 1.1 × 2.8 | 0.8 × 0.8 × 2.2 | |
| Hamano—VOXELAP           |               | 11 × 0.74 | |
| Polhemus—Fastscan        |               | 2 × 2 | |
**Vision device**

Although the basic triangulation technique is similar for most of the 3D body scanners, they differ in the method of light projection and image capture. A scanning head contains the projection system and imaging system from one viewpoint. Non-contact optical techniques are used in 3D body scanning systems to capture the shape of the subject according to specific vision devices. Vision devices used in 3D scanning include projectors, coupled charged devices (CCD), light sources (LED, laser, etc) and final screen resolution.

As shown in Table 4, most 3D body scanners (Cyberware, TecMath, Vitronic and Hamamatsu) project light horizontally. In a horizontal stripe scanner, the scanning heads move parallel to the longitudinal axis of the body. The Hamano VOXELAN scanner is the only one that uses vertical laser stripes. The VOXELAN projects two vertical laser lines, which move over the body in the horizontal plane. The camera is mounted steady. Some of the systems (TC2, Telmat and Turing) have no moving components. The TC2 and Telmat scanners project structured light stripes on the body.

Cyberware, Vitronic, TecMath, Polhemus and VOXELAN (Hamano) use lasers. The advantage of a laser strip scanning system is that only one line needs to be analysed, unlike light projection (TC2, Telmat, LASS, CogniTens and Hamamatsu) and stereo-photogrammetry (Turing 3D). When Laser strip scanning systems are used on the human body, the laser must be classified as Class 1 for eye safety. Except for the Polhemus (Class 2) system, not currently used in body scanning, available 3D laser scanners are safe.

In the Cyberware, Vitronic and Hamamatsu systems, cameras or mirrors are mounted above and below the projection system. This enables the capture of the top of the head and the chin area. In the TecMath scanner, the cameras are mounted only above the laser projector. This means that the lower side of some body parts may not be well represented.

The Hamano VOXELAN has cameras mounted at a fixed position between rotating laser projectors. Body parts, like the shoulders and crotch, do not show up very well due to camera positioning. The TC2–3T6 system uses six projectors and cameras; three for the upper part of the body and three for the lower part. The front of the body is captured by four cameras and the back by two cameras. As the viewpoint of the scanning head is lower than the shoulder, the top of the shoulder may not show up very well.

Both Telmat and Hamano scan the subject twice. First, the front of the body is scanned, and then the back. Hamano merges the data by using markers on the shoulders. Telmat merges the data by ‘gluing’ the front and back scans on the shadow scan of the body. The disadvantage of this procedure may be image distortion since there is no control for posture differences during the front and back scans (Daanen and Jeroen, 1998).

In order to capture the whole body with structured light, the projector and cameras have to be placed at a significant distance from the body, or multiple scan heads must be used. Unless mirrors are used, the first option increases the size of the total scanning system. Therefore, some companies (such as TC2) use separate scanning heads for the upper and lower part of the body. In the Cyberware scanner, the cameras are integrated into a single unit. Mirrors above and below the laser project their images on a single CCD device. The primary advantage of this arrangement is that fewer cameras are needed. However, the complexity of the analysis increases.

Missing data is a significant problem for most 3D body scanning systems. Shading appears to contribute to this problem. Generally, an increase in the number of cameras used, combined with strategic lighting, reduces the amount of missing data.

**Operating requirements**

As shown in Table 5, most scanning systems operate in SGI or Windows NT PC-based environments. Minimum system
Table 4 Light source and vision devices

<table>
<thead>
<tr>
<th>Light projection systems</th>
<th>System</th>
<th>Vision device</th>
<th>Direction projection</th>
<th>Safe eyes</th>
<th>Resolution (R × H × V in mm)</th>
<th>Light source</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC2—3T6 system</td>
<td>6 Cameras</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Pitch 1 × 2.5 × 2.5</td>
<td>Blue light or dark Room/Color luminance data is Grey scale image</td>
</tr>
<tr>
<td>TC2—2T4 system</td>
<td>4 Cameras</td>
<td>Yes</td>
<td></td>
<td></td>
<td>1 × 2.8 × 2.8</td>
<td></td>
</tr>
<tr>
<td>TC2—2T4s system</td>
<td>4 Cameras</td>
<td>Yes</td>
<td></td>
<td></td>
<td>1 × 2.8 × 2.8</td>
<td></td>
</tr>
<tr>
<td>Hamamatsu—BL</td>
<td>2 PSC, 32 LED per head, 8 projectors</td>
<td>Move vertically</td>
<td>Yes</td>
<td></td>
<td>1 × 7.5 × 5</td>
<td>Light emitting diodes (LED)</td>
</tr>
<tr>
<td>Telmat—SYMCAD</td>
<td>Standard video camera</td>
<td>Instant 3D capture</td>
<td>Yes</td>
<td></td>
<td>0.8 × 1.4 × 1.4</td>
<td>Light strip Must be illuminated by the projected light from the camera unit-bright ambient light cannot be used and very large objects require to be captured in sections.</td>
</tr>
<tr>
<td>Wicks &amp; Wilson—TriForm Body Scan</td>
<td>4 CCD and 4 projectors have mirror system, producing 8 view per body.</td>
<td>Not applicable</td>
<td>Yes</td>
<td></td>
<td>Pitch 1.5 × 1.5 × 1.5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Laser Projection Systems</th>
<th>System</th>
<th>Vision device</th>
<th>Direction projection</th>
<th>Safe eyes</th>
<th>Resolution (R × H × V in mm)</th>
<th>Light source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyberware—WB4</td>
<td>CCD, 8 laser</td>
<td>Horizontal projection/ move vertically</td>
<td>Yes</td>
<td>0.5 × 2 × 5</td>
<td>Laser (Class 1) Color (8 bit R, G, B colour or B:\W luminance data)</td>
<td></td>
</tr>
<tr>
<td>Cyberware—WBX</td>
<td>CCD, 4 lasers</td>
<td>Horizontal projection/ move vertically</td>
<td>Yes</td>
<td>0.5 × 2 × 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitronic—Vitus Smart</td>
<td>Video cameras</td>
<td>Move vertically</td>
<td>Yes</td>
<td>2 × 2 × 2</td>
<td>Laser (Class 1) Lightning tubes calibration plate Laser</td>
<td></td>
</tr>
<tr>
<td>TecMath—RAMSIS</td>
<td>CCD cameras</td>
<td>Move vertically</td>
<td>Yes</td>
<td>3.4 × 3.4 × 3.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hamano—VOXELAN</td>
<td>Two vertical laser line move horizontally Cameras</td>
<td>Vertical and horizontal</td>
<td>No</td>
<td>1 × 1 × 1</td>
<td>Laser (Class II)</td>
<td></td>
</tr>
<tr>
<td>Polhemus—Fastscan</td>
<td>Cameras</td>
<td>Vertical and horizontal</td>
<td>No</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
requirements are generally 200MHZ Pentium, 256 MB RAM, Windows NT4.0, 2GB hard drives, 8X CD-ROM drive, 4MB graphics card, Triton PCI chipset and three serial ports. Many of the scanning hardware manufacturers have developed software to allow automatic measurement extraction from the scanned 3D data. Included in this group are: Cyberware (Cyscan, Cydir, WB, and Digisize), Hamamatsu (Body Lines), Hamano (Voxelan extraction software), TC2 (Body Measurement System), Telmat (SYMCAD), and TecMath (RAMSIS and Contour).

Many of the systems proclaim to have the ability to integrate their measurement data into commercially available apparel CAD systems. Both Telmat and TC2 have successfully integrated with Gerber Technology’s made-to-measure (MTM) CAD software. This system enables direct conversion of size information into custom-
fit patterns and production markers. Batch processing allows a single-step process from order-entry to plotting and cutting (Dewitt, 1994).

RAMSIS by TecMath integrates into the factory design tool ANYSIM. The system operates on a PC platform and uses Quick visualisation software. Visualisation of the 3D figure occurs simultaneously with the measurement extraction process.

Other measurement extraction software packages have been developed in research centres. The ARN-SCAN extraction software was developed under the DLA-ARN program. Laser Design developed the Data Sculpt software, Beecher Research Company developed SHAPE ANALYSIS, and Clemson Apparel Research (CAR) developed 3DM.

The SHAPE ANALYSIS (Beecher) and TECMATH-VITUS software have been written to manually extract anthropometric measurements from pre-marked (or landmarked) digitised images.

The 3DM software package has been in the process of development at Clemson University since 1991. It takes 3D whole body image files in text format and provides the user with functions to display, manipulate, segment, analyse and measure the image. It is written in C++, uses OpenGL and X-Windows libraries, and runs on both an SGI workstation running Unix and on a PC running Windows NT (Pargas et al. 1998).

According to a recent study, the 3DM software gives the benefit of accuracy, consistency and reliability of body measurements, as well as improving the quality of garment fit. It extracts measurements based on pre-identified body landmarks.

Conclusion

Three-dimensional whole body scanners have significant potential for the apparel industry, worldwide. They can provide speedy, consistent and accurate data to redefine sizing systems so that they more closely match the current shapes of human bodies. They will also be essential for employment of mass customisation strategies for those companies driven by consumer markets. There are problems yet to be solved that will have an impact on the adoption of this technology. Reducing or eliminating the landmarking process, missing data, and inconsistencies related to movement artefacts are goals held by most of the developers of this technology. A great deal of work remains to be done related to integration of extracted measurements into commercially available apparel CAD systems. Study should also be undertaken on how this technology might support virtual dressing or garment try-ons, as well as on the technical approach used in software development, testing and evaluation.

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Istook and Hwang
Subject: RE: Regarding Vol 5 and number 2
From: "Charles Parker" <CParker@emeraldinsight.com>
Date: Fri, November 7, 2003 4:57 am
To: shwang@unity.ncsu.edu

Dear Su-Jeong

Your Permission Request

Isook, Cynthia L. and Hwang, Su-Jeong. (2001) "3D body scanning systems with
application to the apparel industry", Journal of Fashion Marketing and
Management,
Vol. 5, No. 2.
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CHAPTER V

RESULTS AND DISCUSSIONS IN OBJECTIVE 2:
AN ANALYSIS OF THE CURRENT BODY MEASUREMENT STANDARDS

The current problems with body measurement standards were identified by analysis of the existing body measurement standards. Results from the research outlined in Objective 2 have been published in TI 2002 Conference preceding, and are attached (“Body measurement standards for use with 3D body scanning for apparel development”, TI2002 Conference Preceding in Egypt).

It will be noted that there are inconsistencies in body measurement terminology from one standard to the next. This is problematic for suppliers of body scanning systems, apparel CAD and other software tools.

< Inserted the paper as published. >
BODY MEASUREMENT STANDARDS FOR USE WITH 3D BODY SCANNING FOR APPAREL DEVELOPMENT

Su-Jeong Hwang and Cynthia L. Istook
North Carolina State University, Raleigh, NC, USA

In the apparel industry, garments customized for fit are directly tied to the availability of a comprehensive, accurate set of measurements for each interested consumer. To obtain accurate physical measurements, set of skills is required. Even though 3D body scanners have potential for mass customization strategies to be employed in the apparel industry, without the clarity of standard body measurement terminology, the method can be inaccurate. The paper evaluated body measurement terminology and methods used in the apparel industry. From this evaluation inconsistencies and potential problems were uncovered. In addition, current technical and education references were compared with standards.

1. INTRODUCTION

A very important first step in determining correct sizing or creating customized garments is obtaining accurate measurements of the specific human body. A standard body measurement method is essential for apparel manufacturers in order to produce the customized garments. Without the clarity of standard body measurement terminology, the method can be time consuming, invasive, and often inaccurate, based on who took the measurements and how they took them.

The development of three dimensional body scanning technologies may have significant potential for use in the apparel industry, for a number of reasons. First, this technology has the potential of obtaining an unlimited number of linear and non-linear measurements of human bodies in a matter of seconds. Because an image of the body is captured during the scanning process, the location and description of the measurements can be altered as needed in mere seconds, as well. Second, the measurements obtained using this technology have the potential of being more precise and reproducible than measurements obtained through the physical measurement process. Third, with the availability of an infinite number of linear and non-linear measurements the possibility exists for garments to be created to mold to the three dimensional shapes of unique human bodies. Finally, the scanning technology allows measurements to be obtained in a digital format that could integrate automatically into apparel CAD systems without the human intervention that takes additional time and can introduce error. Ultimately, it may enable the industry to produce mass customized garments.

In 1998, the Civilian American and European Surface Anthropometry Resource program (CAESAR) at Wright-Patterson Air Force Base initiated the largest scale anthropometric survey performed in over 30 years. It is the first international survey of its kind to utilize body-scanning technology. The Cyberware WB4 whole body scanner was used in this study (CAESAR, 1999). The collected data would be used by multiple industries, including the military, automotive, and apparel. The three-dimensional body scanning technologies are already being used in the apparel industry. Levi-Strauss has placed a scanning system in their San Francisco, California store and has experimented with the production of made-to-measure jeans. Brooks Brothers has used measurements extracted from scanned bodies to produce their own customized shirts.
Textile Clothing Technology Corporation (TC2) of Cary, North Carolina, a non-profit organization funded in part by the government, has focused a significant amount of research and development time and effort on 3D body scanning and measurement extraction. This organization is committed to aiding in the development of technologies that will support the American apparel industry (TC2, 2000). Telmat developed SYMCAD in the framework of a partnership with the French Navy (Soir, 1999). Hamamatsu developed the BL scanner for the women’s upper torso using tight undergarments in Japan. Telmat and Hamamatsu have size selection tables have been developed based on ISO 8559. Telmat has a size selection table based on ISO 8559 and the coordination of integrated garment ensembles or package. The system has demonstrated how measurements could be stored and delivered to the ultimate user with their ISO standard (Telmat, 2000). The resulting measurement data can be integrated into apparel CAD systems.

However, unfortunately, most sizing systems that have developed through the years are neither standardized nor related to the average human body measurements. Most people have a problem with fit in the clothing that is currently available in the marketplace, in one way or another. Many have learned to make do with the garments available for purchase by avoiding certain features that always cause a fit problem with their different than average figures or by obtaining the service of tailors or alterations specialists. This underlying dissatisfaction provided impetus to the birth of the paradigm of mass customization.

The purpose of this study was to evaluate body measurement terminology and methods used in the apparel industry. From this evaluation inconsistencies and potential problems were uncovered. Standards for apparel sizing were collected from ASTM D 5219 and ISO 8559 that has been used for developing 3D body scanners. In addition, current technical and education references were compared with the standards.

2. RESEARCH METHOD

Standard terminology and body measurement methods for apparel sizing were collected from ASTM D 5219-99, ISO 8559 and anthropology. ASTM D 5219-99 standard terminology relating to body dimensions for apparel sizing is based on ISO 8559 relating to garment construction and anthropometric surveys for body dimension, and ISO 3635 relating to size designation of clothes, definitions and body measurement procedures. These two standard body measurement methods used for apparel were based on traditional anthropology (Clauser, C.E., et al., 1986). In addition, current body measurement methods used for technical references (Technical Reference, 1998), education references (Armstrong, 1987), and Auto CAD patterns (Miller, P.B., 1994) were compared with the standard body measurement methods. All measurement terminology and methods were categorized into girth, length, and width and we analyzed them in following seven cases:

- NA: Not available terminology and methods in any standard
- S: All the same terminology and methods
- DTM: Different measurement terminology and methods
- DT: Different terminology but same methods
- DM: Different methods but same terminology
- ASTM: Only available terminology and method in ASTM
- ISO: Only available terminology and method in ISO
3. RESULTS
3.1 Analysis of Overall Standards

As shown in Table 1, the results from this analysis were NA 45.22%, S 11.30%, DTM 18.26%, DT 10.43%, DM 6.09%, ISO 6.96% and ASTM 1.74%. Only a few definitions in girth and length matched each other with the same terminology and the same methods. Technical references for the apparel industry, education, Auto CAD pattern development, and anthropometry showed that 45.22% of total body measurement parts were not in either of two standards. Different terminology and methods (DTM) significantly impacted other parts of measurements or fit. Waist girths and lines with unclear landmarks caused different lengths. The interpretation of that meaning will significantly impact fit.

Table 1. Analysis of Overall Standards

<table>
<thead>
<tr>
<th>Cases</th>
<th>Girth</th>
<th>Width</th>
<th>Length</th>
<th>Total</th>
</tr>
</thead>
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<td>Cases</td>
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<td>25.22%</td>
<td>23</td>
<td>63</td>
</tr>
<tr>
<td>NA</td>
<td>5</td>
<td>17.24%</td>
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<td>31</td>
</tr>
<tr>
<td>ISO</td>
<td>2</td>
<td>6.90%</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>ASTM</td>
<td>0</td>
<td>0%</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>DT</td>
<td>3</td>
<td>10.34%</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>DM</td>
<td>7</td>
<td>24.14%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>DTM</td>
<td>4</td>
<td>13.79%</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>S</td>
<td>8</td>
<td>27.59%</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

Figure 1. The percentage of overall cases in standards
3.2 Girth

Figure 2 displays the percentage of cases in girth. In the category of girth, the results from this analysis were S 27.59%, DM 24.14 %, NA 17.24%, DTM 13.79%, DT 10.34%, ISO 6.9 % and ASTM 0 %. In this category of girth, same measurement terminology and standards were available but still different measurement methods in girth were considerably bigger percentage than other cases.

![Pie chart](image)

**Figure 2. The percentage of cases in girth**

For example, same terminology but different measurement method were bust/chest and thigh max. Bust and chest were defined as same terminology but different methods even in the two major standards.

**Bust/Chest**
- Bust: The circumference of the body over the fullest part of the breasts and parallel to the floor (ASTM D5219)
- Chest: The circumference of the body over the shoulder blades, under the arms and across the upper chest. (ASTM D5219)
- Bust/Chest: The maximum horizontal girth measured during normal breath with the subject standing upright and the tape measure passed over the shoulder blades, under the armpits, and across the nipples (ISO 8559)

**Thigh max**
- The *maximum circumference* of the upper leg close to the crotch (ASTM D5219)
- The horizontal girth measured, without constriction, *at the highest thigh position*, with the subject standing upright (ISO8559)

The following definitions of Neck and Waist are examples of the different terminology and methods (DTM) in girth.
Neck (Mid Neck or Neck base)

- Mid Neck: Circumference of the neck approximately 25mm above the neck base (ASTM D 5219)
- Neck base: The girth of the base of the neck measured using the chain which passes over the base of the 7th cervical vertebra, the neck shoulder points and the medial superior borders of the left and right clavicles (ISO8559)
- Neck: The girth of the neck measured using the tape measure passed round below the Adam’s apple and at the level of the 7th cervical vertebra (ISO8559).
- Neck: taken just over the larger vertebrae at the center back and over the collar bone in the front (Technical References)

Waist (Natural waist or waist circumference omphalion)

- Waist: The circumference of the immediately below the lowest rib.(ASTM D 5219)
- Waist: The girth of the natural waistline between the top of the hip bones and the lower (ISO 8559)
- Waist circumference omphalion: measure the horizontal distance around the torso at the level of the center of the navel (Anthropometric)
- Waistline: Entire natural waistline. Keep the tape measure snug, but tuck two fingers beneath it (Technical References).
- Waistline: Take a firm but tight measurement (Education References)

The definition of Neck referred different locations in standards, technical and educational references. Technical references and educational references referred Neck to Neck base but ISO 8559 referred Neck to Mid Neck. The definition of waist had same problems with confusion of the location. The bust circumference/shoulder breadth, and waist front length are the key measurements for upper torso garments (Chun-Yoon and Jasper, 1996). Therefore, Waist girths with unclear landmarks caused different lengths. The interpretation of that meaning will significantly impact fit.

3.3 Width

Figure 3 displays the percentage of cases in width. In the category of girth, the results from this analysis were NA 70 %, DTM 22 %, DT 4 %, ASTM 4 %, S 0 %, DM 0 %, and ISO 0 %. In this category, 70 % of width were appeared in the anthropometry, technical and educational references but were not included in any of standards. For example, the following widths were appeared: Back neck, Front neck, Front shoulder, Back shoulder, Front waist, Back waist, and leg width. The higher percentage of NA case can be explained that most of them were defined as girth in the current standards. However, the definitions of width were needed to be specified for developing 3D body scanning systems.
Different terminology and methods (DTM) were Shoulder (Across shoulder or Biacromial breadth), Cross chest width (Chest breadth or Across chest), Cross back width (Interscye), and abdomen (Abdominal extension, or Front high-hip). The following definitions of shoulder and abdomen were examples in this case of DTM.

Shoulder (Across shoulder or Biacromial breadth)
- Across shoulder: The distance from shoulder joint to shoulder joint across the back (ASTM D 5219)
- Shoulder width: The horizontal distance between the acromion extremities (ISO 8559)
- Biacromial breadth: ….. The measurement is taken at the maximum point of quite respiration. Use sufficient pressure to maintain firm contact with the skin (Anthropometry)
- Cross shoulder: Horizontal width measured from shoulder point to shoulder point… (Technical references)

Abdomen (Abdominal extension or Front high-hip)
- Front high hip: The distance from one imaginary side seam to the other imaginary side seam at the high hip level (ASTM D 5219)
- Placing the tape measure midway between the waist line and hip line measure across the abdomen from side seam to side seam (Technical references)

In this category, there were two significant problems. The one was the shoulder joint that was based on “feel” by hand and the other one was imaginary lines such as “side seam to side seam” appeared as unclear descriptions for abdomen width in ASTM. Those traditional methods would not be sufficient description for the 3D body scanning system.
3.4 Length

Figure 4 displays the percentage of cases in width. In the category of girth, the results from this analysis were NA 48 %, DTM 19 %, DT 13 %, ISO 10 %, S 8 %, ASTM 2 %, and DM 0 %. In this category, 48% of length were appeared in the anthropometry, technical and educational references but were not included in any of standards. For example, the following lengths were appeared: Back shoulder slop, Side back to waist, Spine to elbow length, Forearm length, Side seam length, Center front waist to knee, Center front waist to floor, Neck height, Buttock knee length, center front skirt length, Span, and Sleeve cap length. The higher percentage of NA in length can be explained that most definitions were very much specified in the apparel references, but current standards did not include all of them.

![Pie chart showing percentage of cases in length](image)

**Figure 4. The percentage of cases in length**

In the category of length, different terminology and methods (DTM) were Waist length (Waist front length, Waist front length omplion, or Center front length), Side front to waist (Front waist length, Full front length, or Front bodice full length), Front shoulder slop (Shoulder slope, or Center front waist to shoulder), Shoulder length (Side shoulder), Arm length (Sleeve length, or Sleeve out seam), Arm length center back neck to wrist (Sleeve length or cervical to wrist), Bust points around neck (cervical to breast point or strap length), and Side waist to floor (Waist height, or Outside leg length).

Some of different terminology and methods in lengths were caused by other definitions in width and girth. For example, the waist length was not clearly defined like waist width because of the unclear location of the waistline. The different definitions of waist effected to all other related measurements such as side front to waist length, Front Shoulder slope, and Side waist to hips. The problems of finding imaginary line and ‘feel’ by hand were also found in the length definitions. A different starting point for measurements causes fit and inconsistency of measurements. For example, the following definitions of Side waist to floor and Arm length implicated these problems.
Side waist to floor (Waist height)
- Waist height: Measure from the waist level at the sides of the body following the contour of the body to hip level, then vertically to the soles of the feet. (ASTM 5219)
- Waist height: The vertical distance from the natural waist level to the ground, ... (ISO 8559)
- Waist height natural indentation: Measure the vertical distance between the standing surface and the drawn landmark at right waist natural indentation (Anthropometry)
- Side waist to floor: Along the side of the body measure from the lower edge of the waist line tape to the floor (Technical references)
- Side waist to floor: Side of the body from the waist line to the floor (Education references)

Arm length (Sleeve length, or Sleeve out seam)
- Arm length: With the arm bent at 90 degrees and the clenched fist placed on the hip, the distance from the shoulder joint along the outside of the arm over the elbow to the greatest prominence on the outside of the wrist (ASTM D 5219)
- Arm length: The distance from the arm's center /shoulder line intersection, over the elbow, to the far end of the prominent wrist bone, with the subject’s right fist clenched and placed on the hip, and with the arm bent at 90 degree (ISO 8559)
- Sleeve out seam: ... measure the straight line distance between the drawn acromion landmark and the drawn styliion landmark... (Anthropometry)
- Shoulder to wrist: From shoulder top dot over the slightly bent elbow to the wrist bone (Technical references)
- Overarm length: shoulder tip over elbow to mid-wrist bone (Education references)

In the arm length, the different position with arm bent will cause different measurement results. The arm bent for the measurement methods would not be appropriate for the 3D body scanning systems.

4. CONCLUSIONS AND SUGGESTIONS
In our findings, the ISO 8559 and other traditional body measurement methods had three limitations on description. First, traditional body measurement methods for apparel have been based on “feel” by hand. Measurements based on feel only work when the measurer is trained to know what he or she is feeling or when the body is not too padded to cover important landmarks. Second, to measure elbow girth, shoulder to elbow length, and arm length, a bent arm was necessary. Different measurement methods and definitions of arm length appeared in all traditional standard measurements for apparel because the length can be obtained in different positions. And third, imaginary lines such as “side seam to side seam” appeared as unclear descriptions for abdomen width in ASTM.

We found that there was a lack of consensus of terminology and acceptance of standard measurements for apparel. Therefore, a set of measurement standards is needed for both apparel producers and 3D body scanning system developers in the future. Standardization of body
measurements in different industries relating to apparel will increase efficiency in CAD garment sizing, pattern development, and alteration process.

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Subject: RE: Need written permission
From: "sarah tinsley" <sarah@textileinst.org.uk>
Date: Tue, November 18, 2003 4:56 am
To: "Su-Jeong Hwang Shin" <shwang@unity.ncsu.edu>

Dear Su-Jeong Hwang,

Thank you for your email. I am pleased to confirm that we are able to grant permission for you to include your paper, Body Measurement Standards for use with 3D body scanning for Apparel Development in your dissertation paper.

We wish you luck with your dissertation.

Yours sincerely

Sarah Tinsley
CHAPTER VI

RESULTS AND DISCUSSIONS IN OBJECTIVE 3:
METAPHOR MATCHING PROCESS (MMP) SET OF IDENTIFICATION
CODES FOR BI-DIRECTIONAL INTERPRETATION

An important step in pattern alteration or pattern making processes using body
scan measurement data is to have a bi-directional communication and interpretation
process. This is referred to as the Metaphor Matching Process (MMP), a term that has
been developed during this research outlined in Objective 3. The MMP sets out the
Identification Codes that will be used to represent the specific body measurements with
semantics and syntax for both 3D body scanning systems and apparel CAD systems.

It will be noted that the body measurements are simplified to a set of codes
containing 32 body codes with a minimum of 7 descriptive characters: ‘Category’,
MMP has been presented to the ASTM D13.55 committee and at the IFFTI Hong Kong
conference in November, 2002. The final MMP is discussed below:

Metaphor Matching Process (MMP) Model

The Metaphor Matching Process (MMP) Model was based on Lofting’s
mathematical approach (1992). The approach was one of methods for mapping analogy
and metaphor. Analogy was when we say that part of X resembles Y. Analogy has its
root in the Greek word ‘analogia’ meaning ‘proportion’. In analogy there was no
replacement, only aspectral comparison, and implied in this is that if X resembles Y in
certain state, there was a chance that other similar states would also be found. Therefore,
Metaphor Matching Process (MMP) was developed based on the approach theory, and considered following problems and forces that had to be prioritized.

<Problems>:

- Different semantics for measurement terminology in the apparel industry
- Lack of consensus of syntax in the apparel industry
- No real standard available in the field of 3D body scanning as a new technology of measurement
- No rules of creation or steps of matching metaphors for standardization of body measurements existed.

<Forces>:

- Understanding target idea and sources
- Being precise and clear
- Mapping of the elements from target idea to a metaphor
- The logical event flow between elements in the metaphor and target idea should match.

The forces were the main concentration for developing the Metaphor Matching Process (MMP). In the MMP, a set of Identification Codes for each semantic (meaning of each body part) was developed for describing landmarks on the human body by analyzing of a database containing critical body measurements for apparel applications.

**A Set of Identification Codes**

The main idea of ‘Identification Codes’ is to replace existing generic ‘whole’ and ‘aspects’ terminology of a human body by symbolizing the raw concept of a body. Each
code means an aspect of a human body to describe a whole body. A hierarchy of body measurement Identification Codes in a database was created in that all additional facades are within the initial context (‘whole’ and ‘aspects’) and the whole and its aspects are differentiated so that each metaphor of a human body contains a pattern that is based on the intended way it is created. Table 5 shows Identification Codes for body measurement terminology as each ‘Part’. These body part’s Identification Codes were used in the element ‘Body_Code’ in the MMP XML program.

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<td>AD</td>
<td>Abdomen</td>
</tr>
<tr>
<td>2</td>
<td>AH</td>
<td>Armhole</td>
</tr>
<tr>
<td>3</td>
<td>AK</td>
<td>Ankle</td>
</tr>
<tr>
<td>4</td>
<td>AM</td>
<td>Arm</td>
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<td>5</td>
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<td>Armpit</td>
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<td>6</td>
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<td>Bicep</td>
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<tr>
<td>7</td>
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<tr>
<td>27</td>
<td>SY</td>
<td>Scye depth</td>
</tr>
<tr>
<td>28</td>
<td>TH</td>
<td>Thigh</td>
</tr>
<tr>
<td>29</td>
<td>TR</td>
<td>Trunk</td>
</tr>
<tr>
<td>30</td>
<td>WR</td>
<td>Wrist</td>
</tr>
<tr>
<td>31</td>
<td>WS</td>
<td>Waist</td>
</tr>
<tr>
<td>32</td>
<td>WT</td>
<td>Weight</td>
</tr>
</tbody>
</table>
**The Syntax Used in the MMP model**

Syntax with the Identification Codes was developed for describing in detail body parts’ location. Every body description is from the view point of the person, not the viewer. The syntax had an order of description of each part, and six minimum characters of MMP ID with seven descriptive characters were required for describing body parts. The minimum characters of MMP ID included: Body code (2) + Category (1) + Location1 (1) + Location 2 (1) + Location 3 (1). Table 6 shows syntax as a rule of body measurement description and each minimum number of characters.

**Table 6. Syntax for developing MMP terminology**

<table>
<thead>
<tr>
<th>No.</th>
<th>Body code</th>
<th>Category</th>
<th>Location 1</th>
<th>Location 2</th>
<th>Location 3</th>
<th>Move direction</th>
<th>Amount</th>
<th>Measure unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Identification code</td>
<td>g=girth</td>
<td>f=front</td>
<td>1=left</td>
<td>1=left</td>
<td>*.+= toward to negative direction</td>
<td>180</td>
<td>in =inch</td>
<td></td>
</tr>
<tr>
<td>= Body measurement terminology</td>
<td>b=back</td>
<td>1=left</td>
<td>2=right</td>
<td>1=left</td>
<td>*.+= toward to negative direction</td>
<td>0.06</td>
<td>cm=cm</td>
<td></td>
</tr>
<tr>
<td>e.g, WS=waist</td>
<td>l=length</td>
<td>2=right</td>
<td>0=center</td>
<td>1=left</td>
<td>*.+= toward to negative direction</td>
<td>90</td>
<td>cm=cm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>w=width</td>
<td>x=not applicable</td>
<td>x=not applicable</td>
<td>x=not applicable</td>
<td>x=not applicable</td>
<td>x=not applicable</td>
<td>d=degree</td>
<td></td>
</tr>
</tbody>
</table>

The syntax began with 2 characters of body code that identified each body part. In the measurement category, the ‘g’ indicates girth, ‘l’ indicates length, ‘w’ indicates width, and ‘p’ indicates point. The point ‘p’ was related to landmarks in most descriptions of whole body measurements. The first location was focused on torso and legs. In the identified first location, ‘b’ indicated back, ‘f’ indicated front, and ‘s’ indicated side. This location was not applicable for describing the location of arms. For example, elbow points were considered in a back position, but the first location of wrists
could not be defined. In this case, ‘x’ indicated the case, and the second location was used for description of arms and legs.

In the second location, detail of torso was not applicable. The description of second location would be left, right, or not applicable. For example, shoulder neck left point was equal to [SNpsx1]. These locations are expressed as numbers (0, 1, and 2) because ‘left’ could be same code as ‘length’. The third location was for a description of detail locations from first location and second location. For example, left knee point would be equal to [KNp1f0]. After the location description, negative sign (-) or positive sign (+) indicated moving direction from any given point or line. At this point, any required amount of moving position was expressed within 4 characters with 2 characters of measurement units.

In this study, most MMP IDs and Landmark IDs could be explained with the syntax. In addition, girth, length, or width of body measurement could be described with each related landmark or point. More than two MMP IDs or Landmark IDs were used for describing the whole body measurements following the additional syntax in Table 7. The additional syntax was not a requirement, but it was very important for shortening the description of body measurements.

Table 7. Syntax of extending description of body measurements with MMP ID

<table>
<thead>
<tr>
<th>No. of characters</th>
<th>Portion of Body</th>
<th>MMP ID</th>
<th>Link Locations</th>
<th>MMP ID</th>
<th>Line Types</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>max= Max</td>
<td></td>
<td>3</td>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>mid= Mid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>min=Mini</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/2= Half</td>
<td>SNpsx1= Shoulder neck point left side</td>
<td>1</td>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>&quot;=&quot;= where to where</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;=&quot;= between</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@= at</td>
<td>SDpsx1= Shoulder point left side</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( )pa = parallel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( )cu = curve to a body</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
If necessary, body category codes in Table 6 such as girth, width, and length were combined with body measurement descriptions in Table 7. As shown in Table 7, the portion of body was expressed as max, mid, min, or half portion of any given body part’s location, and each MMP ID or landmark ID with 6 characters had linkages such as ‘where to where’ (=_), ‘between’ (=-), and ‘at’ (=@). Then, at the end, if necessary, line types of the girth, width, or length were indicated with a parallel or a curve to a body. The additional required information of line type was compared to any given category. While the linkage expression is necessary for describing whole body measurements, degree angle (= d) is occasionally required for specific measurements such as arm bent, waist line level, or shoulder slope. For example, [maxBCgs1x@/(SDpsx1~ELpb10)] means the maximum circumference of the arm usually midway between the elbow and the shoulder joint.

Body measurement terminologies from each different standard ASTM and ISO as a “whole” terminology were stored in the database (MMP.mdb) and analyzed “whole body” concept into “body parts” and matched each “parts” to Identification Code in the template. In this Metaphor Matching Process (MMP), each different body term was able to match with the same concept of a body. For example, shoulder neck left point is matched to SNpsxl as shown in the Chapter III Methodology (See Figure 47).

As a result, each body measurement terminology semantic followed the same format and was matched with simple syntax for easy referencing. This method permitted a structural way of finding a MMP consensus. It is simple to understand and provided guidance in applying to the concept of the metaphorical systems in general.
**Landmarks in the MMP Model**

A landmark is a mark placed on a human body used to identify the origin, endpoint, or level of a measurement (Clauser, C., et al. 1986). In this experiment using the MMP model, the following forces were considered for selecting landmarks.

- **Clarity:** Landmarks have to be clearly understood.

- **A point, not a line:** A landmark is a point. A line can be explained with at least two points.

- **Relation with each specified body measurement:** All body measurements can be explained with the fundamental landmarks.

- **Apparel applications:** This process focuses on apparel applications such as creation or alteration of garments. Some definitions might not be applicable to other applications such as medical uses and anthropometry research because the selection of landmarks depends on the application. For example, in the field of anthropometry requires a very specific body part such as ‘Bimalleolar breadth’. However, the measurement is not necessary for apparel applications.

- **Minimize number of landmarks:** Even though a body scanning system provides a point cloud with thousand of points, all points are not necessary. Working with all points would be overly time consuming.

  Body measurements in the category of girth, length, and width in the database (MMP.mdb) were changed to point descriptions, from a point to a point. For example, back waist length $= \text{[WSlbx0]} = \text{[NKpbx0\_WSpbx0]}$. In the result, 41 points and 2 side imaginary lines were found. Table 8 shows each selected landmark with its
corresponding ‘Body_Code’. The MMP codes were based on the ‘Body_Code’ previously developed with MMP model. These codes were considered as very important primary keys for programming or integrating data.

Table 8. Landmarks with Body_Codes

<table>
<thead>
<tr>
<th>No.</th>
<th>Body_Code</th>
<th>Landmark_ID</th>
<th>Terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AK</td>
<td>Akps11</td>
<td>Ankle left side left point</td>
</tr>
<tr>
<td>2</td>
<td>AK</td>
<td>Akps12</td>
<td>Ankle left side right point</td>
</tr>
<tr>
<td>3</td>
<td>AK</td>
<td>Akps21</td>
<td>Ankle right side left point</td>
</tr>
<tr>
<td>4</td>
<td>AK</td>
<td>Akps22</td>
<td>Ankle right side right point</td>
</tr>
<tr>
<td>5</td>
<td>AP</td>
<td>APpx1</td>
<td>Ankle left point</td>
</tr>
<tr>
<td>6</td>
<td>AP</td>
<td>APpx2</td>
<td>Ankle right point</td>
</tr>
<tr>
<td>7</td>
<td>BR</td>
<td>BRpx1</td>
<td>Break point left back</td>
</tr>
<tr>
<td>8</td>
<td>BR</td>
<td>BRpx2</td>
<td>Break point right back</td>
</tr>
<tr>
<td>9</td>
<td>BR</td>
<td>BRpx1</td>
<td>Break point left front</td>
</tr>
<tr>
<td>10</td>
<td>BR</td>
<td>BRpx2</td>
<td>Break point right front</td>
</tr>
<tr>
<td>11</td>
<td>BU</td>
<td>BUpx1</td>
<td>Bust left point</td>
</tr>
<tr>
<td>12</td>
<td>BU</td>
<td>BUpx2</td>
<td>Bust right point</td>
</tr>
<tr>
<td>13</td>
<td>CR</td>
<td>CRpx0</td>
<td>Crotch point</td>
</tr>
<tr>
<td>14</td>
<td>EL</td>
<td>Elpb10</td>
<td>Elbow left point</td>
</tr>
<tr>
<td>15</td>
<td>EL</td>
<td>Elpb20</td>
<td>Right elbow point</td>
</tr>
<tr>
<td>16</td>
<td>FL</td>
<td>FLps11</td>
<td>Floor left</td>
</tr>
<tr>
<td>17</td>
<td>FL</td>
<td>FLps22</td>
<td>Floor right</td>
</tr>
<tr>
<td>18</td>
<td>FL</td>
<td>FLpx0</td>
<td>Floor center</td>
</tr>
<tr>
<td>19</td>
<td>FT</td>
<td>FTps11</td>
<td>Foot left side left point</td>
</tr>
<tr>
<td>20</td>
<td>FT</td>
<td>FTps12</td>
<td>Foot left side right point</td>
</tr>
<tr>
<td>21</td>
<td>FT</td>
<td>FTps21</td>
<td>Foot right side left point</td>
</tr>
<tr>
<td>22</td>
<td>FT</td>
<td>FTps22</td>
<td>Foot right side right point</td>
</tr>
<tr>
<td>23</td>
<td>HD</td>
<td>HDpx0</td>
<td>Head point</td>
</tr>
<tr>
<td>24</td>
<td>HP</td>
<td>HPpx0</td>
<td>Hip center back point</td>
</tr>
<tr>
<td>25</td>
<td>HP</td>
<td>HPpx1</td>
<td>Hip center front point</td>
</tr>
<tr>
<td>26</td>
<td>HP</td>
<td>HPpx2</td>
<td>Hip right side point</td>
</tr>
<tr>
<td>27</td>
<td>KN</td>
<td>KNpx10</td>
<td>Knee left point</td>
</tr>
<tr>
<td>28</td>
<td>KN</td>
<td>KNpx20</td>
<td>Knee right point</td>
</tr>
<tr>
<td>29</td>
<td>NK</td>
<td>NKpx0</td>
<td>Neck center back point</td>
</tr>
<tr>
<td>30</td>
<td>NK</td>
<td>NKpx1</td>
<td>Neck center front point</td>
</tr>
<tr>
<td>31</td>
<td>SD</td>
<td>SDpx1</td>
<td>Shoulder left point</td>
</tr>
<tr>
<td>32</td>
<td>SD</td>
<td>SDpx2</td>
<td>Shoulder right point</td>
</tr>
<tr>
<td>33</td>
<td>SM</td>
<td>SMlsx1</td>
<td>Side imaginary line left</td>
</tr>
<tr>
<td>34</td>
<td>SM</td>
<td>SMlsx2</td>
<td>Side imaginary line right</td>
</tr>
<tr>
<td>35</td>
<td>SN</td>
<td>SNpx1</td>
<td>Shoulder neck left point</td>
</tr>
<tr>
<td>36</td>
<td>SN</td>
<td>SNpx2</td>
<td>Shoulder neck right point</td>
</tr>
<tr>
<td>37</td>
<td>WR</td>
<td>WRpx11</td>
<td>Wrist left point</td>
</tr>
<tr>
<td>38</td>
<td>WR</td>
<td>WRpx22</td>
<td>Wrist right point</td>
</tr>
<tr>
<td>39</td>
<td>WS</td>
<td>WSpbx0</td>
<td>Waist center back point</td>
</tr>
<tr>
<td>40</td>
<td>WS</td>
<td>WSpfx0</td>
<td>Waist center front point</td>
</tr>
<tr>
<td>41</td>
<td>WS</td>
<td>WSpdx1</td>
<td>Waist left side point</td>
</tr>
<tr>
<td>42</td>
<td>WS</td>
<td>WSpdx2</td>
<td>Waist right side point</td>
</tr>
</tbody>
</table>

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In the Table 8, the side imaginary lines [SMLsx1, SMLsx2] were defined as lines which divide the front of the body from the back of the body. The side imaginary lines were created from shoulder points ([SDpsx1], [SDpsx2]) and drawn to the floor (perpendicular). The lines were used for finding side points in the upper body except wrist points on arms [WRpx11, WRpx22] and elbow points [ELpb10, ELpb20] (see Figure 53).

The floor [FLpxx0] was defined as the soles of the feet as ASTM and ISO defined the term. The [FLpxx0] was a center position that was commonly expressed with X=0, Y=0, Z=0 coordinates on the screen of the body scan (See Figures 51 and 52). In the lower body parts, side hip points [HPsx1, HPsx2] were based on side imaginary lines [SMLsx1, SMLsx2]. The side imaginary lines were used for a body torso. However, it was difficult to define the side imaginary line because lower body parts and arms moved more often than a body torso. Figures, 51, 52, and 53 show the specific landmark locations on the 3D body scans.
Figure 51. A front of the 3D body scan with codes
Figure 52. A back of the 3D body scan with codes
Critical Measurements for Basic Patterns

Landmarks with ‘body codes’ in the database (MMP.mdb) were applied for describing critical measurements for apparel patterns. The critical measurements must be basically known in order to create or alter apparel patterns. The selection of the critical body part measurements from whole body measurements could be different by considering pattern methods, style of garments, sex, and age. However, in this study, only critical body measurements for adult women’s basic patterns were used with ‘Body codes’ in MMP model in order to demonstrate the relationship between landmarks’ body codes and each specified body measurements.

- Bodice: shoulder width, bust girth, chest width, back waist length, and waist girth.
- Skirts: waist girth, hip girth, side waist hip length, high hip girth, and skirt length.
- Pants: waist girth, hip girth, side waist hip length, vertical waist height, inseam length, crotch depth, and pants length.
- Sleeves: Sleeve length, Armhole length, and wrist girth.

The selected critical measurement terms each had a body code, and the body codes were replaced with landmarks’ body codes as point descriptions. Tables 9, 10, 11, and 12 show two different types of body codes for each body measurement term appearing in a basic pattern. The abbreviated body codes were based on the ISO and ASTM terminology. On the other hand, the body codes with landmarks’ indication show the codes based on the body measurement definitions. For example, the shoulder width body code, [SDwbxx], was replaced with a new body code that contained its landmarks.
[SDpsx1 -- > SDpsx2]. The selection of the landmarks was based on the body measurement definitions.

Table 9. Critical measurements for creating a basic bodice pattern

<table>
<thead>
<tr>
<th>Patterns</th>
<th>Terminology</th>
<th>Abbreviated body codes</th>
<th>Body codes with Landmarks</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bodice</td>
<td>Shoulder width</td>
<td>SDwbxx</td>
<td>[SDpsx1_SDpsx2]</td>
<td>The distance from shoulder point to shoulder point across the back.</td>
</tr>
<tr>
<td></td>
<td>Bust Girth</td>
<td>[Bwxxx]</td>
<td>[BUpfx1_BUpfx2_BUpfx1]pa</td>
<td>The circumference along the horizontal line at the fullest point of the bust, going over the shoulder blades, under the arms (back-break point), and across the bust points.</td>
</tr>
<tr>
<td></td>
<td>Chest Width</td>
<td>CHwfxxx</td>
<td>[BRpfk1_BRpfk2]</td>
<td>The horizontal width across the front of the body taken from armhole to armhole. Take measurement at the half waypoint between the shoulder and the underarm, this generally falls 3&quot; below the Center front neck point.</td>
</tr>
<tr>
<td></td>
<td>Back Waist Length</td>
<td>WSlb0</td>
<td>[NKpbx0_WSpbx0]</td>
<td>The vertical length taken from center back neck point to back waist point on the waist girth line.</td>
</tr>
<tr>
<td></td>
<td>Waist Girth</td>
<td>WSgxxx</td>
<td>[WSpbx1_WSpbx0_WSpbx2_(WSpfx0)cu_WSpbx1]</td>
<td>The horizontal line at the natural waist, which is the narrowest point around the torso, below the bottom rib and above the hipbones.</td>
</tr>
</tbody>
</table>

As shown in Table 9, all critical measurements for creating bodice pattern had abbreviated body codes, and the body codes could be expressed with their landmarks.

However, in a basic sleeve pattern, two limitations were considered for application with this same method. First, the arm length required arm bent in 90 degrees. Second, desired sleeve length had a start landmark point, but desired end points could be variable.

For the first solution, a degree angle had to be added into the body codes with landmarks. For example, arm length had abbreviated body codes, [AMlx1x+90de]. The body code with landmarks was expressed as [SDpsx1_ELpb10+90de_WRpx11]. For the second solution, the desired length remained as an ‘Absolute value’ length. For example, sleeve length had abbreviated body codes, [Sleevel], and the body code with landmarks
was expressed as [SDpxs1]_Absolute Value. Table 10 shows the results for the description of the basic sleeve pattern.

Table 10. Critical measurements for creating a basic sleeve pattern

<table>
<thead>
<tr>
<th>Patterns</th>
<th>Terminology</th>
<th>Abbreviated body codes</th>
<th>Body codes with landmarks</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleeves</td>
<td>Arm Length</td>
<td>[Amlx1x+90de]</td>
<td>[SDpxs1_ELpb10+90de_WRpx11]</td>
<td>With the arm bent at 90° and the clenched fist placed on the hip, the distance from the shoulder joint along the outside of the arm over the elbow to the greatest prominence on the outside of the wrist.</td>
</tr>
<tr>
<td></td>
<td>Wrist Girth</td>
<td>[WRgx1x]</td>
<td>[WRpx11_WRpx12_WRpx11]</td>
<td>The circumference over the prominence of the inner and the outer forearm wrist bones.</td>
</tr>
<tr>
<td></td>
<td>Armhole</td>
<td>[AHgsx1]</td>
<td>[SDpxs1_BRpxfs1_APpxs1_BRpxs1_SDpxs1]</td>
<td>The distance from the shoulder joint through the front-break point, the armpit, the back-break point, and to the starting point.</td>
</tr>
<tr>
<td></td>
<td>Sleeve length</td>
<td>[Sleevel]</td>
<td>[SDpxs1]_Absolute Value</td>
<td>The distance from the shoulder joint along the outside of the arm to the desire sleeve length.</td>
</tr>
</tbody>
</table>

Table 11 shows critical measurements for creating a basic skirt pattern. Skirt length included an absolute value for the desired length.

Table 11. Critical measurements for creating a basic skirt pattern

<table>
<thead>
<tr>
<th>Patterns</th>
<th>Terminology</th>
<th>Abbreviated body codes</th>
<th>Body codes with landmarks</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skirts</td>
<td>Waist Girth</td>
<td>[WSgxxx]</td>
<td>[WSpxs1_WSpxs0_WSpxs2_(WSpxs0)cu_WSpxs1]</td>
<td>The horizontal line at the natural waist, which is the narrowest point around the torso, below the bottom rib and above the hip bones.</td>
</tr>
<tr>
<td></td>
<td>Hip Girth</td>
<td>[HPgxxx]</td>
<td>[maxHPgxxx@(WSgxxx-CRpxx0)]</td>
<td>The circumference along the horizontal line at the points of the hip, across the fullest part of the buttocks and over the upper end of the thigh bone.</td>
</tr>
<tr>
<td></td>
<td>High Hip Girth</td>
<td>[(HHgxxx)pa]</td>
<td>[(WSpxs0-3in_WSpxs0-3in_WSpxs0-3inpa)]</td>
<td>The circumference of the body at a point approximately 7.5 cm (3 in.) below the waist and parallel to the floor.</td>
</tr>
<tr>
<td></td>
<td>Side Waist Hip Length</td>
<td>[WSpxs1_HPpxs1]</td>
<td>[WSpxs1_HPpxs1]</td>
<td>Taken at the side of the body from the side waist point to the fullest part of the side hips.</td>
</tr>
<tr>
<td></td>
<td>Skirt length</td>
<td>[Skirtl]</td>
<td>[WSpxs0]_Absolute Value</td>
<td>Measure from front waist point to desired skirt length.</td>
</tr>
</tbody>
</table>
Table 12 shows critical measurements for creating a basic pants pattern. Body codes with landmarks were applied to the measurement description. Pants length included an absolute value for the desired length. In traditional measurement methods, a sitting position is required to take a crotch depth measurement. However, body scan systems do not require a sitting position. For the solution, the body code with landmarks for crotch depth was expressed with the following formula because crotch depth length is equal to the difference between vertical waist height and inseam length.

\[
\text{Crotch depth length} = [WSp_{x1} - CR_{pfx1} ] \\
= [(WSp_{x1} - FL_{psx11}) - (CR_{pfx0} - FL_{pdx0})]
\]

<table>
<thead>
<tr>
<th>Patterns</th>
<th>Terminology</th>
<th>Abbreviated body codes</th>
<th>Body codes with landmarks</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pants</td>
<td>Waist Girth</td>
<td>[WSgxxx]</td>
<td>[WSp_{x1} - WSp_{x0} - WSp_{x2} - (WSp_{x0} - cu - WSp_{x1})]</td>
<td>The horizontal line at the natural waist, which is the narrowest point around the torso, below the bottom rib and above the hip bones.</td>
</tr>
<tr>
<td></td>
<td>Hip Girth</td>
<td>[HPgxxx]</td>
<td>[max HPgxxx@ (WSp_{x0} - CR_{pfx0})]</td>
<td>The circumference along the horizontal line at the points of the hip, across the fullest part of the buttocks and over the upper end of the thigh bone.</td>
</tr>
<tr>
<td></td>
<td>Side Waist Hip Length</td>
<td>[WSp_{x1} - HP_{psx1}]</td>
<td>[WSp_{x1} - HP_{psx1}]</td>
<td>Taken at the side of the body from the side waist point to the fullest part of the side hips.</td>
</tr>
<tr>
<td></td>
<td>Vertical Waist Height</td>
<td>[WSp_{x0} - FP_{pdx0}]</td>
<td>[WSp_{x0} - FP_{pdx0}]</td>
<td>Center front waist to floor. Taken down the middle of the front of the body from the front waist point to the floor.</td>
</tr>
<tr>
<td></td>
<td>Inseam Length ( =Crotch Height)</td>
<td>[CR_{pfx0} - FL_{pdx0}]</td>
<td>[CR_{pfx0} - FL_{pdx0}]</td>
<td>Taken down the inside of the leg from the crotch to the floor.</td>
</tr>
<tr>
<td></td>
<td>Crotch Depth Length</td>
<td>[WSp_{x1} - CR_{pfx1}]</td>
<td>[(WSp_{x1} - FL_{psx11}) - (CR_{pfx0} - FL_{pdx0})]</td>
<td>Crotch Depth Length= Vertical Waist Height - Inseam Length.</td>
</tr>
<tr>
<td></td>
<td>Pants length</td>
<td>[Pants]</td>
<td>[WSp_{x0} - Absolute Value]</td>
<td>Measure from front waist point to desired pants length.</td>
</tr>
</tbody>
</table>

These examples of the body codes with a few landmark points had the consistency of defining body measurement terminology, and demonstrated the
relationship between landmarks’ body codes and each specified body measurement. This means that body codes with a few landmark points were enough to define terminology and process because of the consistency of the syntax rules.

**Examinations of the MMP Identification Codes**

The application of MMP Identification Codes was examined by using SQL in the database (MMP.mdb) that contained two entity tables of body measurement standards: ISO 8559 and ASTM 5219. Each table contained the following elements: Terms, Definitions, and MMP codes. The MMP Identification Codes were based on the standards’ definitions, rather than terms (see Figure 54). In the database, following two queries were executed, and Table 10 shows the SQL statements for this experiment and the results.

- **SQL 1:** Body measurement terminology matching numbers by inter-join terms in each standard table.

- **SQL 2:** Body measurement terminology matching numbers by inter-join MMP Identification Codes in each standard table.

![Diagram](image)

**Figure 54:** An experimental design for the examination of the MMP Identification Codes
Table 13. SQL matching body parts and SQL matching with MMP

<table>
<thead>
<tr>
<th>Queries</th>
<th>SQL statements</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>SQL 1: Matching body parts only</td>
<td>SELECT [ASTM5219].[Terms], [ISO8559].[Terms] FROM ASTM5219 INNER JOIN ISO8559 ON [ASTM5219].[Terms]=[ISO8559].[Terms];</td>
<td>Matching 20 body parts</td>
</tr>
<tr>
<td>SQL 2: Matching body parts with MMP Identification Codes</td>
<td>SELECT ASTM5219.MMP_ID, ISO8559.MMP_ID, ASTM5219.Terms, ISO8559.Terms FROM ASTM5219 INNER JOIN ISO8559 ON ASTM5219.MMP_ID = ISO8559.MMP_ID;</td>
<td>Matching 37 body parts</td>
</tr>
</tbody>
</table>

As shown in the Table 13, SQL2 matching body parts with MMP identification found more matching terms than SQL1 matching body parts with only each body measurement standard’s terms. This means some body parts in the standard had different terminology but they meant the same body parts. Table 14 shows the detailed results of body measurement terminology and definitions found in only SQL2, but not in SQL1.

Table 14. The results of body measurement terms and definitions found in only SQL2

<table>
<thead>
<tr>
<th>NO.</th>
<th>MMP ID</th>
<th>ASTM D5219</th>
<th>ISO 8559</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(WSpx1_FLPx11)cu-(CRpx0_FLPxx0)</td>
<td>true rise</td>
<td>Body rise</td>
</tr>
<tr>
<td>2</td>
<td>(WSpx1_FTpx11)cu</td>
<td>outside-leg length</td>
<td>outside leg length</td>
</tr>
<tr>
<td>3</td>
<td>1/2(SDpx1_SNpxs1)_CRpx0_Bupfx1_1/2(SDpx1_SNpxs1)</td>
<td>total vertical trunk length</td>
<td>trunk circumference</td>
</tr>
<tr>
<td>4</td>
<td>APsx1_APsx2_APsx1</td>
<td>upperchest girth</td>
<td>chest girth</td>
</tr>
<tr>
<td>5</td>
<td>APsx1_WRpx12</td>
<td>underarm length</td>
<td>under arm length</td>
</tr>
<tr>
<td>6</td>
<td>BUpfx1_BUpfx2</td>
<td>bust point to bust point</td>
<td>bust width</td>
</tr>
<tr>
<td>7</td>
<td>CRpx0_FLPx0</td>
<td>inside-leg length</td>
<td>crotch height</td>
</tr>
<tr>
<td>8</td>
<td>maxHPgxx@((WSgxx=CRpxx0))</td>
<td>hip</td>
<td>hip girth</td>
</tr>
<tr>
<td>9</td>
<td>NKpx0_SNpxs1_BUpfx1</td>
<td>cervicale to bust point</td>
<td>cervical to breast point</td>
</tr>
<tr>
<td>10</td>
<td>NKpx0_WSpbx0</td>
<td>center back waist length</td>
<td>back waist length</td>
</tr>
<tr>
<td>11</td>
<td>SDpx1_BRpx1_APpx1_BRpx1_SDpx1</td>
<td>armhole</td>
<td>armscye girth</td>
</tr>
<tr>
<td>12</td>
<td>SDpx1_BRpx1_APpx1_BRpx1_SDpx1</td>
<td>armscye circumference</td>
<td>armscye girth</td>
</tr>
<tr>
<td>13</td>
<td>SDpx1_ELpb10+90de</td>
<td>upper-arm length</td>
<td>upper arm length</td>
</tr>
<tr>
<td>14</td>
<td>SDpx1_SDpx2</td>
<td>across shoulder</td>
<td>shoulder width</td>
</tr>
<tr>
<td>15</td>
<td>SNpxs1_NKpx0_SNpxs2_NKpx0+1in_SNpxs1</td>
<td>mid-neck girth</td>
<td>Neck girth</td>
</tr>
<tr>
<td>16</td>
<td>WSpx1_WSpbx0_WSpx2_WSpx2_WSpx0_WSpfx0cu_WSpx1</td>
<td>waist</td>
<td>waist girth</td>
</tr>
<tr>
<td>17</td>
<td>WT</td>
<td>body weight</td>
<td>Body mass</td>
</tr>
</tbody>
</table>
CHAPTER VII

RESULTS AND DISCUSSIONS FOR OBJECTIVES 4 AND 5: BODY MEASUREMENT DATA FORMAT DEVELOPMENT AND STRUCTURE FOR STANDARIZATION

Standardization of body measurement data with XML (eXtensible Markup Language) and XSD (XML Schema) was developed, and the data connectivity for possible integration of body scan systems and apparel CAD systems using IDEF1X model has been demonstrated. The research outlined in Objectives 4 and 5 are discussed below.

**Body Measurement Data Format Development for Standardization (Objective 4)**

The experimental design of body measurement data file format with XML (eXtensible Markup Language) developed a standard method by which body measurement terminology can be interpreted bi-directionally from data generated by optical 3D body measurement devices and 2D CAD pattern generation systems. In this study, MMP XML and XSD (XML schema) were programmed and used for communication between a body scan supplier and an apparel CAD supplier. In 2003, [TC]² and Gerber Technology, Inc. participated in this experiment study. [TC]² provided customizable body measurement definitions, and Gerber Technology, Inc. was developing XML CAD pattern data in collaboration with the ASTM D.13.66 committee.

**Previous Studies on Standardization with XML**

There are few studies on implementation of XML in apparel industry, and the use of XML was found in standards development. The World Wide Web Consortium (W3C), the international standards organization that developed HTML, reviewed XML as
a meta-grammar that allows for web automation and data interchange across multiple platforms and applications (Matsumura, 1998). According to Matsumura (1998), XML must be a universal data grammar and syntax language because the XML is structured, self-describing, extensible, and viewer adaptive. XML is a very structured language specification, and XML documents utilize a DTD or XSD for defining the syntax, grammar and data structure of XML documents (Matsumura, 1998). With these characteristics, XML naturally became a standard language.

Attempts at standardization of 2D and 3D body measurement representation with XML were found in the e-T Cluster (IST-2000-26084) project that researched the development of a common standard for the representation of human bodies. The XML data format, called BodyXML (Kartsounis, G. et al., 2002), was expected to open up the possibilities of a Sizing Survey in UK. The standardization development of the e-T Cluster was on two levels: the definition of a common set of body measurements for apparel, and definition of formats for the exchange of this information with BodyXML (Kartsounis, G. et al., 2002).

The BodyXML was designed to interpret the world of ‘bodies’, ‘persons’, ‘garments’ and ‘products’, and provide a high level representation. In addition, it was to form the infrastructure of a generic, inclusive, high level data wrapper that allows a diverse collection of formats to be combined with the meta-information that was necessary for the development of complete, non-trivial applications (Kartsounis, G. et al., 2002). In the e-T Cluster (IST-2000-26084) project, XML was ideally suited to the purposes because it was an open standard that allows the definition of structures and the
external referencing of low-level files (Kartsounis, G. et al., 2002). Figure 55 shows the structure of the application domain that was used for the e-T Cluster project.

![Diagram of Person and Product structures]

**Figure 55.** Structure of the application domain (Kartsounis, et al., 2002)
As shown in Figure 55, the following key concepts were embodied in BodyXML on an individual person and an identifiable product range.

- Person: A uniquely identifiable human being (i.e. person name with birth date)
  - Details: A set of meta-information about a person
  - Representation: A representation of a person (e.g. “bggs.tfm”, “jblg002.wrl”, “jbl987.blz”)

- Product: A collection of garments to be marketed as one entity (e.g. “Otto Shirt”)
  - Details: A set of information that accompanies the physical description of the garment (e.g. target market information, manufacturer, retail outlets, stock information)
  - Representation: A representation of a specific garment (e.g. size 8, red, image JPEG)

The arrangement levels for body representation followed an earlier proposal by Tecmath AG (Human Solutions GmbH) for multiple-level representation. The arrangement was to enable applications and system developers to use whichever file format they could fit for their application, without being required to use a specific format, but also without compromising interoperability between systems (Kartsounis, G. et al., 2002). Figure 56 shows the arrangement levels for body representation.
As shown in Figure 56, geometry levels in the arrangement of body representation include the following levels:

- Level 0: Raw binary (usually proprietary) point cloud with holes (e.g. BLS – not for general use)
- Level 1: Raw point cloud with holes, in a generic, text based, human-readable form (e.g. VRML, XYZ, TXT)
• Level 2: Cleaned unconnected point cloud with holes, in a generic, text based, human-readable form (e.g. VRML, XYZ, TXT)
• Level 3: Cleaned connected point cloud with holes, in a generic, text based, human-readable form (e.g. VRML, XYZ, TXT)
• Level 4: Complete SGMA-compliant surface (triangulated or parametric, e.g. h-anim)
• Level 5: Complete animate SGAA-compliant surface (e.g. h-anim 2.0, MPEG-4).

These levels defined a hierarchy of placeholders for 3D representations. The BodyXML (developed as part of the e-T Cluster project) was tested with the CAD interoperability standard (developed as part of the e-Tailor project) in a configuration combining systems developed by both projects. The following systems were used for generating data: Telmat scanner; Tecmath AG (Human Solutions GmbH) scanner; AvatarMe booth; Lectra CAD system; Investronica MTM ordering and CAD systems. The following systems read the data: Lectra CAD system; Investronica CAD system; and the AvatarMe fashion show system (Kartsounis, G. et al., 2002).
Figure 57 shows the diagram of the data flow. As shown in Figure 57, the chain of interoperability shows a uni-directional linear structure from Scan-to-Pattern-to-Garment-to-Animated-Dressed-Avatar. The results from the study demonstrated the suitability of XML as a generic, tolerant, flexible and customisable mechanism for exchange of information within this collection of diverse hardware and software and
software systems (Kartsounis, G. et al., 2002). The ability of XML as a syntax for information content and a placeholder of information held in files of other formats made it the ideal interoperability infrastructure for integrated application required for the e-T Cluster project.

However, the interoperability infrastructure limits standardization of the body measurement data format with XML since it was based on a uni-directional linear structure that had to be understood from body scan suppliers to virtual design companies in the data flow. In this case, XML was not applied for standards development but used only for information transaction.

**Experiment Design of Body Measurement Data Standardization with MMP XML**

In this experimental design of body measurement data standardization, XML format was used for bi-directional interpretation and communication between a 3D body scan system and a 2D apparel CAD system. Body measurement data with XML (eXtensible Markup Language) format, MMP XML, and the schema, MMP XSD were developed for standardization of critical measurements from a 3D body scanning system into and out of a 2D CAD system.

In the design of standardization with XML, the MMP XSD schema was centered as a main controller for validation of XML documentations including MMP XML, body scan XML, and pattern data XML. The MMP XSD rules were based on the previous MMP model. The MMP XML was validated with the schema and suggested to CAD suppliers and body scan suppliers as a viable format.
Figure 58. Structure of standardization body measurement data flow with MMP XML

Figure 58 shows the structure of the standardization body measurement data flow with XML format. As shown in Figure 58, the MMP XSD (schema) was centered for standardization with rational rules in the design. The MMPXSD development started from current available multi-standards that were found as references to body scan suppliers, pattern makers, and researchers. According to the MMP XSD, the suggested MMP XML was programmed and suggested to body scan suppliers and CAD suppliers.
The XML with MMP XSD would guide the transfer of data with its descriptions or information since there was no way to add references into data with current file formats.

Even though MMP XML would be available for most suppliers, this experimental design has considered the possibility of extending XML data format to include different body scan suppliers and CAD suppliers. The reason is that one of XML characteristics is self-defining and most suppliers still look up the multi-standards as references that might cause various results while using XML. However, MMP XSD schema would be required for validating any XML. Body scan suppliers and CAD suppliers could use either MMP XML or their own XML that was validated with MMP XSD. Theoretically, once the schema validated any XML format, then the suppliers could understand each other.

In addition, this design included alternate process with other compatible data file format such as databases, documentation, and HTML. It might also be available to virtual design developers, e-commerce developers, and apparel manufacturers who might not have XML data format. Through the process of open design structure with the main source of XSD schema, ultimately, MMP XML with the XSD would encourage users to a consensus for transfer of data.

**MMP XML and XSD**

For this experimental design, previously developed MMP identification codes in the database (MMP.mdb) were programmed into an MMP.xsd file that was required for XML format and validation. Further, MMP XML (MMP.xml) with the XSD (MMP.xsd) was developed for transmission of body measurement data. Then, the developed XML format (MMP.xml) with the XSD (MMP.xsd) was sent to [TC]² and Gerber Technology,
Inc. to determine if it was a viable standard format for body measurement data connectivity to CAD.

**MMP database.** The MMP database included the following elements that had one to many relationships with each other: Body_Part, Landmarks, MMP_List, ASTM 5219, and ISO 8559. The following MMP database IDEF1X model shows the relationship between each element, and each element’s attributes. The bold characters indicated each Primary Key for the relationship (See Figure 59).

![MMP database IDEF1X model](image)

Figure 59. MMP database IDEF1X model

As shown in 59, in the relationship, the Primary Keys (in bold) were unique identifications that were not duplicable in each specified table. These were Body_Code, Landmark_ID, and MMP_ID. Body_Code migrated to Landmarks table, Landmark_ID
migrated to MMP_List table, and MMP_ID in MMP_List table migrated to ASTM 5219 and ISO 8559 for identifying each body measurement term. The MMP_ID is important for reconciling different body measurement terminology with the same definitions as used in the ASTM and ISO standards.

Table 15 shows that the MMP database included the following descriptive elements, attributes, and values. Each element had Code attributes that were part of MMP_ID description. These elements were not included in the relationship shown in Figure 60 but were the rules for writing MMP_ID in MMP schema.

<table>
<thead>
<tr>
<th>No.</th>
<th>Elements</th>
<th>Attributes</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Category</td>
<td>Code</td>
<td>g, l, w, p, x.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Category</td>
<td>Girth, length, width, point, not applicable.</td>
</tr>
<tr>
<td>2</td>
<td>Direction</td>
<td>Code</td>
<td>+, -, x.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direction</td>
<td>Positive move, Negative move, not applicable.</td>
</tr>
<tr>
<td>3</td>
<td>Link_Type</td>
<td>Code</td>
<td>@, ~, .</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Type</td>
<td>At, between, link where to where.</td>
</tr>
<tr>
<td>4</td>
<td>Location 1</td>
<td>Code</td>
<td>f, b, s, x.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Location 1</td>
<td>Front, back, side, not applicable.</td>
</tr>
<tr>
<td>5</td>
<td>Location 2</td>
<td>Code</td>
<td>1, 2, x.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Location 2</td>
<td>Left, right, not applicable.</td>
</tr>
<tr>
<td>6</td>
<td>Location 3</td>
<td>Code</td>
<td>0, 1, 2, x.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Location 3</td>
<td>Center, left, right, not applicable.</td>
</tr>
<tr>
<td>7</td>
<td>Unit</td>
<td>Code</td>
<td>Cm, in, de</td>
</tr>
</tbody>
</table>

**MMP schema.** MMP schema was designed for developing MMP XML. First, schema was created by converting the MMP database from above (The schema location: C:\Dissertation (SU XML)\MMP_XML\MMPDB_XML\01-1 Convert from MMP Database.xsd). Elements were the same as the database’s elements: ASTM 5219;
Body_Part; Category; Direction; ISO 8559; Landmarks; Line_Type; Link_code; Location 1; Location 2; Location 3; Unit; and MMP_List (See Figure 60).

Figure 60. Schema diagram results from the data conversion
Figure 60 shows an example schema diagram of the results from the data conversion. As shown in Figure 60, all elements in the database were successfully converted to the XML format. XML declaration is a line of code at the beginning of an XML document that identifies the version of XML used by the document. Since there is only one version of XML currently (version 1.0), the standard XML declaration for XML 1.0 was used for this study.

However, a limitation of restructuring the database model was found in this research. The research indicated that an assigning root element is required for XSD (XML schema). For this reason, redesign of the conversion schema model from the database (MMP database.mdb) was necessary. An element called ‘MMP’ was assigned as a root element that has four sub-elements: ‘Body_Part’, ‘Descriptive_Codes’, ‘Landmarks’, and ‘MMP_List’. Figure 61 shows the structure diagram of elements, and Figure 62 shows the main element’s schema (see Figures 61 and 62).
As shown in Figure 62, four sub-elements were branched from a root element that linked each element. Elements that have maxOccurs = “unbounded” in Figure 62, ‘Body_Part’, ‘Landmarks’, and ‘MMP_List’, permitted the addition of an unlimited number of values from the same elements in order for a XML writer to list more than one value in an element. All main sub-elements were used as element references since they were related to other elements in the MMP XSD. For example, a referenced element,
‘Landmarks’, could be a sub-element from the main element, ‘Body_Part’ (see Figure 63).

![Figure 63. A structure of a ‘Body_Part’ element and the sub-elements](image)

Figure 64 shows the detail of the ‘Body_Part’ element’s schema. A sub-element of ‘Body_Part’, ‘Body_Code’, was a key for an identity constraint. ‘Terms’ for any body measurement terminology could be identified with the key ‘Body_Code’ that was already created in the previous MMP model.

```xml
<xsd:element name="Body_Part">
  <xsd:complexType>
    <xsd:sequence>
      <xsd:element name="Body_Code">
        <xsd:simpleType>
          <xsd:restriction base="xsd:string">
            <xsd:maxLength value="5"/>
          </xsd:restriction>
        </xsd:simpleType>
      </xsd:element>
      <xsd:element name="Terms">
        <xsd:simpleType>
          <xsd:restriction base="xsd:string">
            <xsd:maxLength value="30"/>
          </xsd:restriction>
        </xsd:simpleType>
      </xsd:element>
      <xsd:element ref="Landmarks" minOccurs="0" maxOccurs="unbounded"/>
    </xsd:sequence>
  </xsd:complexType>
  <xsd:complexType>
    <xsd:key name="Body_Part_Body_Code">
      <xsd:selector xpath="."/>
      <xsd:field xpath="Body_Code"/>
    </xsd:key>
  </xsd:element>
</xsd:element>
```

![Figure 64. ‘Body_Part’ element’s schema](image)

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A ‘Landmarks’ element has five sub-elements: ‘Landmark_ID’, ‘Terms’, ‘Body_Code’, ‘Description’, and ‘MMP_List’. Figure 65 shows the structure of ‘Landmarks’ element with the sub-elements.

Figure 65. A structure of ‘Landmarks’ element with five sub-elements

One of the sub-elements, ‘Landmark_ID’, was an identified constraint key for the ‘Landmarks’ element. Figure 66 shows a part of the ‘Landmark_ID’ element schema.

```xml
<xs:element name="Landmarks">
  ...
  ...
  <xs:element ref="MMP_List" minOccurs="0" maxOccurs="unbounded"/>
  </xs:sequence>
<xs:complexType>
<xs:key name="Landmarks_Landmark_ID">
  <xs:selector xpath="."/>
  <xs:field xpath="Landmark_ID"/>
</xs:key>
</xs:element>
```

Figure 66. Identified constraint key for ‘Landmarks’ element

Since a sub-element, ‘Body_Code’ was an identified constraint key for ‘Body_Parts’ element, it allowed the ‘Landmarks’ elements to match with ‘Body_Parts’ elements. Each constraint key was used as a Primary Key to establish each element’s
relationship in the schema. This method was a recreation of the relationship shown in the previous MMP Database. ‘MMP_List’ was a sub-element in the ‘Landmarks’ element and also the ‘MMP_List’ was a main element for seven sub-elements: ‘Terms’, ‘MMP_Term’, ‘MMP_ID’, ‘Landmark_ID’, ‘Description’, ‘ASTM5219’, and ‘ISO8559’ (see Figures 67 and 68).

![MMP_List element’s structure in MMP XSD](image)

Figure 67. ‘MMP_List’ element’s structure in MMP XSD

```xml
<xs:element name="MMP_List">
  ...
  ...
  <xs:element ref="ASTM5219" minOccurs="0" maxOccurs="unbounded"/>
  <xs:element ref="ISO8559" minOccurs="0" maxOccurs="unbounded"/>
</xs:sequence>
</xs:complexType>
<xs:element ref="MMP_ID"/>
</xs:element>
```

Figure 68. Identified constraint key for ‘MMP_List’ element
As shown in Figure 68, a sub-element, ‘MMP_ID’, was an identified constraint key in the ‘MMP_List’ element that was expressed as `<“xs:field xpath= MMP_ID”/>` in MMP XSD. Optional elements for sample standards, ‘ISO8559’ and ‘ASTM5219’ in ‘MMP_List’ were referenced and allowed an unlimited number of values `<maxOccurs = “unbounded”>` for later use in the standards.

In MMP XSD, ‘Descriptive_Codes’ elements were added to display each meaning of an MMP_ID. These sub-elements were ‘Category’ of the body measurements such as girth, width, length, and point and location codes of the body parts (See Figure 69).

![Figure 69. ‘Descriptive_Codes’ elements](image)

These were all based on the MMP that was previously created in this research for a set of identification codes. The detail XSD for the elements is shown in the following Figure 70.
As shown in Figure 70, ‘Location_Codes’ elements in the ‘Descriptive-Codes’ included locations, link code terms, line types, and units. These were referenced and allowed an unlimited number of values <maxOccurs = “unbounded”> as option elements for later description of MMP_ID.

**MMP XML.** MMP was written with XML format. Formation and validation of MMP XML were tested with XMLSpy software, and the result showed the MMP XML to be well formed and valid. The following Figure 71 shows a sample from MMP XML (02 MMP.xml).
Figure 71. A sample result from MMP XML

In Figure 71, all body measurement terminology is shown including the MMP ID with tags that explain data values. For example, “across shoulder, SDpx1_SDpx2,
SDpsx1, in body measurements, the distance from shoulder joint to shoulder joint across the back”, the meaning of SDpsx1 alone would not be clear. However, the XML format made clear the meaning of each Identification Code and different term from references such as ISO and/or ASTM.

    <MMP_List>
    <Terms> across shoulder </Terms>
    <MMP_ID> SDpsx1_SDpsx2 </MMP_ID>
    <Landmark_ID> SDpsx1 </Landmark_ID>
    <Description> in body measurements, the distance from shoulder joint to shoulder joint across the back </Description>
    </MMP_List>

The XML format above indicates that SDpsx1_SDpsx2 meant MMP_ID, and SDpsx1 was Landmark_ID. This result indicated that data could be understood with extra explanation in the XML format. This advantage of using XML was applied to body scan measurement data and CAD pattern data.

**Body Scan Data XML and Schema**

MMP XML and MMP XSD were sent to [TC]², and investigated for the acceptability of MMP XML format in the [TC]² system. As a result, the concept of MMP identification for body measurement definitions with XML format could be easily understood at the technical software development level. However, MMP ID characters could not fit in the MEP file that was designed for customizable body measurement definitions since MEP file limits the number of characters. For this reason, a sample
body scan data with a modified MEP file was sent from [TC]², extending the length of character numbers. The [TC]² body measurement data sample was analyzed for developing body scan data XML and its schema.

**Analysis of body scan data in MEP file format.** Original body measurement data from [TC]² was in a MEP file format. The MEP format enabled defining body measurements with editable body measurement parameters. Figure 72 shows an example of waist measurements with parameters.

![Figure 72. MMP ID with waist measurement parameters in MEP file](image)

As shown in Figure 72, waist girth could be defined differently by varying its parameters, and the following Table 16 shows the detailed results from analysis of waist parameters in MEP format.
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Methods / points</th>
<th>Descriptions</th>
<th>Applied areas (semantics)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waist parameters</td>
<td>Center Back Point</td>
<td>Starting height for center back point&lt;br&gt;Upper limit of center back point&lt;br&gt;Lower limit of center point&lt;br&gt;Formula 1 (Option)</td>
<td>Waist&lt;br&gt;Hips&lt;br&gt;Abdomen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>small of back / Formula 1 (selections)</td>
<td>Out seam</td>
</tr>
<tr>
<td>Center Front Point</td>
<td>Upper limit of center front point&lt;br&gt;Lower limit of center front point&lt;br&gt;Front center point is at a fixed from the center back point (Option)</td>
<td>Starting height = crotch height + ( ) * hip circumference + ( ) * hip circumference squared</td>
<td>Vertical Rise&lt;br&gt;Crotch Length&lt;br&gt;Neck to Waist</td>
</tr>
<tr>
<td>Side Points</td>
<td>Amount the side points are allowed to go above a line between the center back point and the center front point: inches Amount the side points are allowed to go below a line between the center back point and the center front point: inches Amount the side points are allowed to vary in height from each other: ( ) inches</td>
<td>Amount the side points are allowed to go above a line between the center back point and the center front point: inches Amount the side points are allowed to go below a line between the center back point and the center front point: inches Amount the side points are allowed to vary in height from each other: ( ) inches</td>
<td>Shoulder to Waist&lt;br&gt;Stomach&lt;br&gt;Bust to Waist</td>
</tr>
</tbody>
</table>

As shown in Table 16, waist parameters were based on three different landmark points such as center back point, center front point and side points. Each landmark point has various methods of description and formulas. For example, the waist level of girth could vary by each point landmark’s location or formula such as formula 1 (Starting height = crotch height + ( ) + ( ) * hip circumference + ( ) * hip circumference²).

In another formula, a user could define upper and lower limit of each point or formula. Waist parameters are applied not only to the waist but also other areas such as hips, abdomen, outseam, vertical rise, crotch length, neck to waist, shoulder to waist, stomach, and bust to waist. This customizable body measurement definition had the advantage of creating body measurement terminology since MEP format allows for users...
to define their own terms. However, this shows a potential conflict in having more than one way of describing the same body measurements. The following example examination of waist girth shows the problem.

**Example examination of waist girth parameters.** The samples were 33 female and 25 male scan data sets from [TC]², and they were tested for waist parameters and consistency of body measurements. Waist parameters in 5 cases were set up with differing amounts of lower limit for center front point and side points (Table 17).

All cases had the same definitions of center back point as the “small of the back” that was a hollow point on the back waist, but the only a different amount of center front point lower limit height reference to center back point. The latitude allowance amount of side points is same for center front point lower limit. Therefore, side points must follow the circumferential line connecting the center back point and center front point. The amount range was from 0 to 3 inches. Table 17 shows the different waist parameters in the 5 cases.

<table>
<thead>
<tr>
<th>Cases</th>
<th>Center back point</th>
<th>Amount lower limit of center front point (inch)</th>
<th>Allowance amount side points (inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WSGxxx</td>
<td>Small of back</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>WSGxxx-0.5inch</td>
<td>Small of back</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>WSGxxx-1inch</td>
<td>Small of back</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>WSGxxx-2inch</td>
<td>Small of back</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>WSGxxx-3inch</td>
<td>Small of back</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
Figure 73. Waist girth results using different center front lower limit settings

Figure 73 shows the results of waist girth measurements by ‘total average’, ‘female average’, ‘male average’ and ‘male_008’ from body scan data extraction by different waist parameter definitions. The results were significantly different using different center front lower limit settings for the waist parameter. Increasing center front lower limit amount decreased waist girth measurements for all body samples. Comparing the ‘male average’ and the ‘female average’ groups, a ‘male average’ group shows a larger difference amount between different center front back limit settings. A sample, ‘Male_008’ shows the greatest variation in waist girth measurement amounts (from 38.53 inches to 42.48 inches).
Figure 74 shows the standard deviation of the waist girth measurements. The X value axis shows sample numbers and the Y value axis indicates standard deviation of waist girth measurements in each sample.

![Graph showing standard deviation of waist girth measurements]

Figure 74. Standard deviation of waist girth measurements

As shown in Figure 74, the resulting range of standard deviation was from 0.01 to 1.55 inches. The highest standard deviation value (1.55) was found in ‘Male_008’ that showed the larger waist girth measurements in previous Figure 73. It can therefore be observed that increasing the center front lower limit settings for larger waist girth customers causes larger variances than for smaller waist girth customers. This indicates
potential problems when defining waist girth measurements. In this research, MMP_ID was used for defining several different waist girth definitions that have been used in current standards (ASTM and ISO). The following example shows the MMP_ID for defining ‘waist girth’:

\[
\text{Waist girth} = \text{WGxxxx} = \text{WSpsx1}_\text{WSpbx0}_\text{WSpsx2}_(\text{WSpfx0})\text{cu}_\text{WSpsx1}
\]

\[
=\text{Waist girth} \neq \text{WGxxxx-1inch} = \text{WSpsx1}_\text{WSpbx0}_\text{WSpsx2}_(\text{WSpfx0} = \text{WSpbx0-1in})\text{cu}_\text{WSpsx1}
\]

This shows the same ‘waist girth’ terminology, but MMP_ID indicates different waist girth. WGxxxx-1inch is different from WGxxxx. WGxxxx-1inch is defined as WSpfx0 (waist point front center) that is 1 inch below from the level of WSpbx0 (waist point back center). MMP_ID provides a short description of the measurement method unlike long verbal descriptions.

**Body scan data XSD.** Sample body measurement data with *.ord file from [TC]² was converted to * .xml file format for body scan data schema. Figure 75 shows a part of the converted file in XML format.

```
<Import>
  <Row>
    <Field1>CUSTOMER=Female_001</Field1>
  </Row>
  <Row>
    <Field1>GARMENT=mmpsetup</Field1>
  </Row>
  <Row>
    <Field1>MEASURE APpxs1_APpxs2_APpxs1=39.84</Field1>
  </Row>
  .
  .
  .
  <Row>
    <Field1>MEASURE SNpxs1_SDpxs1=5.56</Field1>
  </Row>
</Import>
```

*Figure 75.* Imported *.ord file format to *.xml file format
As shown in Figure 75, *.ord file was successfully converted to *.xml file format. However, a schema for body scan data XML format is still necessary for defining elements. For this reason, ‘Body scan data XSD’ was created and based on this conversion of body measurement data. The ‘Body scan data XSD’ includes following main elements:

- ‘Body_Scan_Data’: is a root element;
- ‘Measurements’: contains body measurement data including scan ID, MMP ID, body measurement terminology, measurement amount, and units.
- ‘Scan_Landmarks’: contains body landmarks’ information used in body scanning process, including scan ID, landmark ID, body measurement terminology, XYZ location and units.
- ‘Scan_Company’: contains body scan company information including body scan company name, scanners, and website URL.
- ‘Scan_ID’: is for an identification of a scanned person.
- ‘Scan_List’: contains list of scanned file information in XML documentation including scan ID, measurement file location, scanner resolution, and scanned date.

A root element, ‘Body_Scan_Data’, includes one optional sub-element ‘Scan_Landmarks’ and six required sub-elements: ‘Document_Date’, ‘Document_By’, ‘Contact_C Email’, ‘Scan_Company’, ‘Scan_List’, and ‘Measurements’. ‘Scan_Landmark is an optional element because landmarks’ XYZ locations could not be found in body measurement data from [TC]. However, landmark information may be added by body
scan developers if they have the capability of tracking landmark point location. Figure 76 shows the ‘Body_Scan_Data’ element schema structure.

![Diagram of Body Scan Data Element Structure]

Figure 76. Body scan data element structure
As shown in Figure 76, sub-elements, ‘Document_Date’, ‘Document_By’, and ‘Contact_Email’ are included in ‘Body scan data’ element to show XML documenter’s information and date. Other sub-elements, ‘Scan_Company’, ‘Scan_List’, ‘Scan_Landmarks’ and ‘Measurements’ are referenced and allowed an unlimited number of values for possible duplication of the element themselves. The ‘Scan_Company’ element has extended sub-elements (See Figures 77 and 78).

![Diagram of Scan_Company elements]

**Figure 77.** ‘Scan_Company’ elements in Body scan data XSD

```xml
<xs:element name="Scan_Company">
  <xs:complexType>
    <xs:sequence>
      <xs:element name="Company_Name">
        <xs:simpleType>
          <xs:restriction base="xs:string">
            <xs:maxLength value="50"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
      <xs:element name="Scanner" maxOccurs="unbounded">
        <xs:simpleType>
          <xs:restriction base="xs:string">
            <xs:maxLength value="50"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
      <xs:element name="Website" type="xs:anyURI">
        </xs:element>
    </xs:sequence>
  </xs:complexType>
</xs:element>
```

**Figure 78.** Body scan data XSD for ‘Scan_Company’ elements
As shown in Figures 77 and 78, ‘Scan company’ has 3 sub-elements that show body scan company name, scanners, and website information. ‘Scanner’ elements are unbounded since a body scan company might have more than one body scanner. A ‘Website’ element has to be any URI type for body scan data XML format. A ‘Scan_List’ element structure includes the extended sub-elements: ‘Scan_ID’; ‘Measure_File’; ‘Scan_Date’; ‘Scan_Time’; ‘Scan_By’; ‘Scanner’; and ‘Resolution’ (See Figure 79).

![Diagram of 'Scan_List' elements]

Figure 79. ‘Scan_List’ elements
As shown in Figure 79, sub-element in ‘Scan_List’ elements are related to body measurement data file information. They are all required sub-elements, but except for the ‘Resolution’ element that gives information about body scan figure resolution on the screen. The ‘Resolution’ element was not considered, but the ‘Resolution’ element is included in ‘Body scan data XSD’ because it could be important information for image file conversion. Figure 80 shows the ‘Body scan data XSD’ for ‘Scan_List’ elements.

```xml
<xs:element name="Scan_List">
  <xs:complexType>
    <xs:sequence>
      <xs:element name="Scan_ID">
        <xs:simpleType>
          <xs:restriction base="xs:string">
            <xs:maxLength value="50"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
      <xs:element name="Measure_File">
        <xs:simpleType>
          <xs:restriction base="xs:string">
            <xs:maxLength value="50"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
      <xs:element name="Scan_Date" type="xs:date">
        <xs:complexType>
          <xs:restriction base="xs:string">
            <xs:maxLength value="50"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
      <xs:element name="Scan_Time" type="xs:time">
        <xs:complexType>
          <xs:restriction base="xs:string">
            <xs:maxLength value="50"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
      <xs:element name="Scan_By" type="xs:string">
        <xs:complexType>
          <xs:restriction base="xs:string">
            <xs:maxLength value="50"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
      <xs:element name="Scanner">
        <xs:simpleType>
          <xs:restriction base="xs:string">
            <xs:maxLength value="50"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
      <xs:element name="Resolution" minOccurs="0">
        <xs:simpleType>
          <xs:restriction base="xs:string">
            <xs:maxLength value="50"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
    </xs:sequence>
  </xs:complexType>
</xs:element>
```

**Figure 80.** Body scan data XSD for ‘Scan_List’ elements

As shown in Figure 80, the ‘Scan_List’ element is a complex type that uses a sequence of sub-elements and restrictions applied to some sub-elements. For example,
‘Scan_Date’ element must follow ‘Measure_File’ element. The ‘Scan_Date’ element is restricted as a date type that has to be ‘yyyy-mm-dd’ type. The ‘Resolution’ element remains as an optional element but, the ‘Resolution’ element also has a restriction that has to be a string type. This means once the ‘Resolution’ element is included then the restrictions will be applied. The sequence rules are applied to ‘Measurements’ elements. According to the ‘Body scan data XSD’, XML schema, ‘Measurements’ elements come after ‘Scan_List’ elements. Figure 81 shows the ‘Measurements’ element structure with the extended sub-elements: ‘Scan_ID’; ‘MMP_ID’; ‘Terms’; ‘Measure’; and ‘Unit’.

Figure 81. ‘Measurements’ element structure in Body scan data XSD
As shown in Figure 81, the ‘Measurements’ element started with ‘Scan_ID’ that represent a scanned person’s identification. Each person’s body measurements with units will be listed in the ‘Measurements’ element. The body measurement terminology in the ‘Term’ element is recognized by ‘MMP_ID’ elements. The following Figure 82 shows a part of the body scan data XML schema for ‘Measurements’ elements.

```xml
<x:s:element name="Measurements">
  <x:s:complexType>
    <x:s:complexContent>
      <x:s:restriction base="x:s:elementRef type="x:s:string">
        <x:s:maxLength value="255"/>
      </x:s:restriction>
    </x:s:complexContent>
    <x:s:element name="Scan_ID">
      <x:s:complexType>
        <x:s:restriction base="x:s:string">
          <x:s:maxLength value="255"/>
        </x:s:restriction>
      </x:s:complexType>
    </x:s:element>
    <x:s:element name="MMP_ID">
      <x:s:complexType>
        <x:s:restriction base="x:s:string">
          <x:s:maxLength value="50"/>
        </x:s:restriction>
      </x:s:complexType>
    </x:s:element>
    <x:s:element name="Measure">
      <x:s:complexType>
        <x:s:restriction base="x:s:double">
          <x:s:maxLength value="50"/>
        </x:s:restriction>
      </x:s:complexType>
    </x:s:element>
    <x:s:element name="Unit">
      <x:s:complexType>
        <x:s:restriction base="x:s:string">
          <x:s:maxLength value="50"/>
        </x:s:restriction>
      </x:s:complexType>
    </x:s:element>
  </x:s:complexType>
</x:s:element>
```

**Figure 82.** Body scan data XSD for the ‘Measurements’ element

As shown in Figure 82, the ‘Measurements’ element is a complex type that includes its sub-elements and restrictions in an ordered sequence. The ‘Scan_ID’ element is referenced in the ‘Measurements’ element. In the ‘Measurements’ element, most sub-elements are ‘string type’ of characters, but the ‘Measure’ element that shows measurement amount has to be a ‘double type’ of character.
The ‘Scan_Landmarks’ element comes after all the ‘Measurements’ elements in the body scan data XSD. The ‘Scan_Landmarks’ element structure includes the extended sub-elements: ‘Scan_ID’; ‘Landmark_ID’; ‘Landmark_Term’; ‘Location_X’; ‘Location_Y’; ‘Location_Z’; and ‘Unit’ (See Figure 83).

![Diagram of the 'Scan_Landmarks' element structure]

Figure 83. The ‘Scan_Landmarks’ element structure
As shown in Figure 83, the ‘Scan_Landmarks’ element includes ‘Scan_ID’ that has been used in the other elements (‘Scan_List’ and ‘Measurements’). The following Figure 83 shows a schema for the ‘Scan_Landmarks’ elements.

```xml
<xs:element name="Scan_Landmarks">
  <xs:complexType>
    <xs:sequence>
      <xs:element name="Scan_ID">
        <xs:simpleType>
          <xs:restriction base="xs:string">
            <xs:maxLength value="50"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
      <xs:element name="Landmark_ID">
        <xs:simpleType>
          <xs:restriction base="xs:string">
            <xs:maxLength value="50"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
      <xs:element name="Landmark_Term" type="xs:string">
        <xs:simpleType>
          <xs:restriction base="xs:string">
            <xs:maxLength value="50"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
      <xs:element name="Location_X">
        <xs:simpleType>
          <xs:restriction base="xs:string">
            <xs:maxLength value="50"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
      <xs:element name="Location_Y">
        <xs:simpleType>
          <xs:restriction base="xs:string">
            <xs:maxLength value="50"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
      <xs:element name="Location_Z">
        <xs:simpleType>
          <xs:restriction base="xs:string">
            <xs:maxLength value="50"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
      <xs:element name="Unit">
        <xs:simpleType>
          <xs:restriction base="xs:string">
            <xs:maxLength value="50"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
    </xs:sequence>
  </xs:complexType>
</xs:element>
```

**Figure 84.** Body scan data XSD for the ‘Scan_Landmarks’ element

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In the Figure 84, the ‘Landmark_ID’ element is an identification for the ‘Landmark_Term’ that is landmark body measurement term in any user’s definition. The ‘Location_X’, ‘Location_Y’, and ‘Location_Z’ are related to landmark points’ XYZ coordinates in a body on the screen. The ‘Unit’ element indicates units of the numbers that are used in XYZ coordinates. As shown in Figure 84, the ‘Scan_Landmarks’ element is a complex type in an ordered sequence. Its sub-elements such as ‘Scan_ID’, ‘Landmark_ID’, ‘Landmark_Term’, ‘Location_X’, ‘Location_Y’, ‘Location_Z’, and ‘Unit’ are simple types with restriction of the character types.

The ‘Body scan data XSD’ defined all necessary elements that will be used in body scan data XML format. This means that any written body scan data XML documentation has to be validated with the body scan data XML schema, ‘Body scan data XSD’. The schema of body scan data XML (04 Body scan data.xsd) was successfully imported to the MMP XSD (02 MMP.xsd). The imported schema is included in the MMP XSD.

**Body scan data XML.** A sample body scan data set from [TC]² was written with XML format. The body scan data XML format was based on MMP XSD (02 MMP.xsd) that includes ‘Body scan data XSD’. The following Figure 85 shows a part of the body scan data XML format (06 Body scan data.xml).
As shown in Figure 85, MMP XSD (02 MMP.xsd) instead of body scan data XSD (06 Body scan data.xsd) was assigned for body scan data XML format. The schema location appears in the second line of the body scan data XML. Formation and validation of the body scan data XML (06 Body scan data.xml) were tested with the XMLSpy software program. The test results showed that the XML formats were well formed and validated.
**Pattern Data XML and Schema**

First, a pattern data XML schema file (ASTM_SewnProductsDataSchema.xsd) was imported from Gerber Technology, Inc. Then, MMP XML, body scan data XML and MMP XSD were sent to Gerber Technology, Inc. to investigate the acceptability of the format for their CAD system. A pattern data XML schema was being developed by software engineers at Gerber Technology, Inc. (Gerber), but has yet to be completed by the company. For this reason, the imported pattern data XML schema was modified for research Objective 4.

**Analysis of pattern data XSD in Gerber Technology.** A standard for pattern data in ASTM has recently been based on the DXF file format, however, XML is expected to be the future standard format with increasing application of the XML format in business. For this reason, Gerber initiated the development of a body scan data XSD. The pattern data XSD (ASTM_SewnProductsDataSchema.xsd) was imported from Gerber and the elements analyzed. Table 18 shows a list of 16 elements with descriptions, and the relationship of each body measurement data. Descriptions of each element were included in the pattern data XSD format from Gerber, and the relation to body measurement data was based on each element’s description. Their elements were developed mainly for pattern making and for the marker making as required in the apparel manufacturing process. The importance of body measurement data is directly or indirectly related to following elements: ‘PatternData’; ‘GradingData’; ‘MarkerData’; ‘BundleList’; ‘PiecePlacementList’; ‘SizeName’; ‘BundleName’; ‘MarkerOrder’; ‘StylePieceSizeGradedData’.
Table 18. Elements in imported pattern data XSD from Gerber Technology Inc.

<table>
<thead>
<tr>
<th>No.</th>
<th>Elements</th>
<th>Descriptions</th>
<th>Relation to Body Measurement Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PatternData</td>
<td>A collection of pattern pieces and related information that defines a sewn product.</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>GradingData</td>
<td>Grading data.</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>MarkerData</td>
<td>Apparel Marker or Nest.</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>BundleList</td>
<td>This is a list of Bundles in the Marker order. Each Bundle is an instance of a Style and Size, corresponding to one garment.</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>PiecePlacementList</td>
<td>This is a list of all pieces in the Marker. This element gives position information for the Piece. Units for x and y coordinates are specified by MarkerAttributes.</td>
<td>Yes</td>
</tr>
<tr>
<td>6</td>
<td>‘SizeName’</td>
<td>Size name</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>‘BundleName’</td>
<td>The BundleName gives the ‘StyleName’ and ‘SizeName’ for this piece instance.</td>
<td>Yes</td>
</tr>
<tr>
<td>8</td>
<td>‘MarkerOrder’</td>
<td>This structure contains information about the styles, material groups, pieces, sizes, and quantities of each size for the specified material group to be included in the marker.</td>
<td>Yes</td>
</tr>
<tr>
<td>9</td>
<td>‘StylePieceSizeGradedData’</td>
<td>This is part of the ‘MarkerOrder’ that determines which ‘Styles’ and ‘Sizes’ are needed.</td>
<td>Yes</td>
</tr>
<tr>
<td>10</td>
<td>‘PieceName’</td>
<td>Additional pieces may be defined at marking time.</td>
<td>N/A</td>
</tr>
<tr>
<td>11</td>
<td>StyleName</td>
<td>Style name of Individual pieces in the Marker.</td>
<td>N/A</td>
</tr>
<tr>
<td>12</td>
<td>‘MarkerMaterial’</td>
<td>All information about the material to be cut is included in this structure.</td>
<td>N/A</td>
</tr>
<tr>
<td>13</td>
<td>‘NotchDefinition’</td>
<td>Notches with negative depth are cut outside the piece perimeter.</td>
<td>N/A</td>
</tr>
<tr>
<td>14</td>
<td>‘MatchRules’</td>
<td>We need to come back to this area, and decide how we want to represent matching information.</td>
<td>N/A</td>
</tr>
<tr>
<td>15</td>
<td>‘NotchType’</td>
<td>The geometry of these notches can be specified by an angle, depth, and width.</td>
<td>N/A</td>
</tr>
<tr>
<td>16</td>
<td>‘SpliceMarkList’</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

As shown in Table 18, pattern’s XY coordination in the ‘PatternData’, ‘GradingData’ and ‘PiecePlacementList’ elements is the most important source for developing a customized garment integrated to a body scan system. In addition, size information in the ‘MarkerData’, ‘MarkerOrder’, and ‘StylePieceSizeGradedData’
elements are related to sizing systems for grading or marker orders. These elements could be related to body scan measurement data. Even though a 3D figure with XYZ point coordinates cannot be translated into a 2D pattern’s XY point coordinate elements related to sizes, it will be very important information in the integration of a 3D body scan system to a 2D CAD system for customized garment design or alteration. However, the elements related to size and body measurement for the alteration processes were not included in the pattern data XSD required from Gerber.

**Modified pattern data XSD.** The imported pattern data XML schema from the Gerber was modified because elements were not available for description of alterations and size tables. Figure 86 shows a structure of the modified pattern data XML schema (10 Pattern data.xsd).

![Diagram showing the structure of the pattern data XML schema](image_url)

**Figure 86.** Structure of pattern data XML schema
As shown in Figure 86, a root element ‘Pattern’ includes two imported elements (‘PatternData’ and ‘GradingData’ from Gerber Technology, Inc.) and two extended elements (‘Alterations’ and ‘Size_Tables’). Figure 87 shows the imported ‘PatternData’ element and the sub-elements.

Figure 87. Imported ‘PatternData’ element schema from Gerber Technology, Inc.
As shown in Figure 87, the ‘PatternData’ complex type includes style information, pattern pieces, and grade rules. The ‘PatternData’ element includes restrictions. For example, some elements (‘StyleName’, ‘SampleSize’ and ‘GradeRule Table’) are restricted with character type as xs:NMTOKEN. In this case, values of elements have to be capital letters. ‘HistoryNotes’ and ‘PatternDataDetail’ are records of documentation in XML format. These would be useful for tracking pattern data sources. Extended elements (‘Alterations’ and ‘Size_Tables’) are related to an alteration and size table in the system management tool. Figure 88 shows an alteration table in Gerber System Management that contains information on the alteration rule name, alteration types, and pattern XY point movement amounts.

![Image](image_url)

**Figure 88.** An alteration table in Gerber System Management
As shown in Figure 88, the alteration rule name is in capital letters, and alteration types are expressed as XY MOVE; and CCW EXT. Point movements are horizontal or vertical moves as a percentage of the alteration base amount in the Gerber System Management. The following XML schema for alterations was based on elements in this alteration table, but also is considered by other CAD systems (See Figure 89).

In Figure 89, the ‘Alterations’ element includes sub-elements of : ‘Alt_Table’; ‘Unit’; ‘Alt_Rule_Name’; ‘MMP_ID’; ‘Alt_Type’; ‘First_Point’; ‘Second_Point’; ‘X_move’; and ‘Y_move’. These sub-elements were not restricted as xs:NMTOKEN that requires capital letter for characters. Instead, string characters are used for elements. The ‘Unit’ element is designed for point movement amounts. The ‘Alt_Rule_Name’ element is related to an alteration rule name such as ‘WAIST’. An alteration rule name is determined by the user. The ‘MMP_ID’ element is required for matching the terms of an alteration rule’s name with body measurement terms in body scan systems, other CAD systems, or other CAD users. This ‘MMP_ID’ element will be a very important identification to obtain a consensus between body measurements.
Figure 89. ‘Alteration’ element schema
The extended ‘Size_Tables’ element is based on a size table in a Gerber System Management tool. The ‘Size_Tables’ element includes the following sub-elements: ‘SizeName’; ‘Sizeid’; ‘Unit’; ‘Alt_Rule_Name’; ‘MMP_ID’; and ‘Measure’ (see Figure 90).

Figure 90. ‘Size_Tables’ element schema

Figure 90 shows the XML schema for ‘Size_Tables’ elements. The ‘SizeName’ element is a restricted type because it was referenced from the previous pattern data XSD. For example, the ‘SizeName’ with xs: NMTOKEN type can be MISSY, and the
‘Sizeid’ with xs:integer type can be 6. In the Figure 90, the ‘Unit’ element is related to body measurement amounts in a size table. The ‘Alt_Rule_Name’ is referenced and also appears in the alteration rule table. This alteration rule name is related to body measurement terminology such as waist girth, hips, and bust. In this case, the alteration rule name includes the ‘MMP_ID’ element for matching the body measurement terminology. The ‘Measure’ element with xs:double type indicates measurement amounts with double decimal numbers.

As shown in Figures 89 and 90, the ‘MMP_ID’ and ‘Alt_Rule_Name’ are referenced to each other in the ‘Size_Tables’ element and the ‘Alterations’ element. The ‘MMP_ID’ is a common identification for describing body measurements in any system, including CAD systems and 3D body scan systems. In addition, this modified pattern data XSD includes the following imported ‘GradingData’ element from Gerber (see Figure 91).
Figure 91. ‘GradingData’ element schema

Figure 91 shows the ‘GradingData’ element schema and the sub-elements:

‘GradeRuleTableName’; ‘SampleSize’; ‘Sizes’; ‘Rules’; ‘HistoryNotes’;
‘GradeRuleDenominator’; and ‘GradingDataDetails’. The ‘Sizes’ and ‘SampleSize’ are related to the ‘Size_Tables’ element in Figure 90. The ‘HistoryNotes’ and ‘GradeRuleDenominator’ are optional elements for hierarchy information associated with
the grading data. Omission of these elements will not cause any change in the XML format. However, ‘GradingDataDetails’ will be required to keep a record of grading data.

Pattern data XML. Garment pattern pieces include information on pattern pieces, alteration rule tables, and size tables. Alteration rules for the sample garment pieces include descriptions with point numbers, movement types and amount, and percentage of change as entered by the user. A size table includes the body measurements of the customer. Automatic made-to-measure (MTM) systems have setup a procedure identifying specific alteration rules and size tables for a garment pattern. Alteration rules and size tables for a specific pattern are used for creating markers in MTM systems.

Sometimes exchange of this pattern data is necessary between apparel manufactures and CAD suppliers. This means understanding pattern data is very important. However, many pattern makers in the industry are not required to know how to alter patterns and do not know how body measurements directly relate to the development or fit of specific garments (Istook, 2002). At this point, pattern data in XML format will be useful to organize any necessary pattern piece information to alter or create garments in that XML can include definitions of each pattern data value with tagged formats. Sample pattern data is written in XML format for research Objective 4.

Sample pattern pieces were chosen from previous research on enabling mass customization with computer driven alteration methods (Istook, 2002). The sample pattern pieces were written in XML format (11 Sample pattern data.xml), according to the modified pattern data XSD (10 Pattern data.xsd).
Figure 92 shows the sample garment pieces with unique point numbers. The unique point numbers are associated with alteration rules in Figure 93. For example, marked point numbers used to alter the pattern pieces, 2130 at the side waist and 2140 at the armpit, are also shown in Figure 93 (See Figures 92 and 93).

Figure 92. Sample garment pieces with point numbers (Istook, 2002)

![Image of garment pieces with point numbers]

![Image of alteration rules table]

Figure 93. Sample alteration tables in Gerber AccuMark system management
Figure 94 shows the beginning of the sample pattern piece data in XML format that follows the rules and restrictions in the pattern data XML schema (10 pattern data.xsd). The <Pattern xsi:noNamespaceSchemaLocation> indicates schema that were referenced for this pattern data XML. This sample pattern data XML includes pattern style name, vendor information, and detail piece information (See Figure 94).

```xml
<?xml version="1.0" encoding="UTF-8"?>
<Pattern xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:noNamespaceSchemaLocation="C:\Dissertation (SU XML)\MMP.XML\MMPDB.XML\10 Pattern data.xsd">
  <PatternData>
    <StyleName>DRESS</StyleName>
    <VendorName>Gerber Technology Inc.</VendorName>
    <Application>AccuMark</Application>
    <ApplicationReleaseVer>7.6.3</ApplicationReleaseVer>
    <Units>English</Units>
    ...
    </PatternDataDetails>
    <Pieces NumberOfPieces="4">
      <Piece Pid="101">
        <PieceName>SQSHIFTBK</PieceName>
        <PieceQuantity>
          <Lefts>1</Lefts>
          <Rights>2</Rights>
        </PieceQuantity>
        ...
        <GradedNest NumberOfSizes="12" MasterBoundary="Sew">
          ...
        </GradedNest>
        ...<MaterialGroups>
          <Material>Denim</Material>
        </MaterialGroups>
      </Piece>
      ...
      <SampleSize>8</SampleSize>
      <GradeRuleTable>MISY</GradeRuleTable>
    </Pieces>
  </PatternData>
  ...
</Pattern>
```

Figure 94. Pattern data XML example

Each tagged data describes each value that a capability not found in other data formats such as DXF. For example, as shown in Figure 94, ‘SQSHIFTBK’ can be easily understood that it means a piece name and not a style name, looking at the tagged data descriptions such as <PieceName>SQSHIFTBK</PieceName>. In addition, detail piece
information can be seen in the XML format. For example, the number of graded nest sizes is 12, and the master boundary is based on a sew line. The sample size was chosen to be size 8 in MISSY grade rule table. This tagged data format is a simple and easy method to describe ambiguous data values. Figure 95 shows waist alterations in pattern data XML format, and Figure 96 shows reproduced image alteration pattern figures from the pattern data XML format (See Figures 95 and 96).

```xml
<Alterations>
  <Alt_Table>ALTERNISSYCRESDARTS</Alt_Table>
  <Unit>%</Unit>
  <Alt_Rule_Name>WAIST</Alt_Rule_Name>
  <MMP_ID>WSpx1_WSpx0_WSpx2_(WSpx0)cu_WSpx1</MMP_ID>
  <Alt_Type>CCW EXT</Alt_Type>
  <First_Point>2140</First_Point>
  <Second_Point>2130</Second_Point>
  <X_move>0</X_move>
  <Y_move>25</Y_move>
</Alterations>
```

Figure 95. An alteration in the pattern data XML example

Figure 96. Understanding of alterations from the sample pattern data XML format
As shown in Figure 95, the alteration rule name (WAIST) in an alteration table (ALTERMISSYCRESDARTS) has percentage units, and the value of ‘MMP_ID’ element (WSpx1_WSpx0_WSpx2_(WSpx0)CU_WSpx1) indicates waist girth. This ‘MMP_ID’ is useful for the description of the waist since the Gerber Accumark system limits the length of characters for alteration rule names. As shown in Figure 96, according to the pattern data XML for an alteration, the first alteration point (2140) is held stationary. Every point is going counter-clockwise from the first point (2140) until the second move alteration point (2130) moves vertically 25% that is difference between the person’s measurements and the base amount. Figure 97 shows the size code table, and Figure 98 shows an example of a size code table in pattern data XML format (See Figures 97 and 98).

![Size Code Table](image)

**Figure 97. Basic size code table (Istook, 2002)**

```xml
<Size_Tables>
  <SizeName>MISSY_DRESS</SizeName>
  <SizeId>4</SizeId>
  <Unit>inch</Unit>
  <Alt_Rule_Name>WAIST</Alt_Rule_Name>
  <MMP_ID>WSpx1_WSpx0_WSpx2_(WSpx0)CU_WSpx1</MMP_ID>
  <Measure>25.93</Measure>
</Size_Tables>

**Figure 98. A size table in the pattern data XML example**

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Figure 98 shows an example of a size table in the sample pattern data XML. It represents a part of the basic size 4 for ‘MISSY_DRESS’ in Figure 97. The alteration rule name in Gerber has a limited number of characters. This might cause miscommunication of measurements. In this case, the ‘MMP_ID’ element clarifies and interprets the specified measurement. According to the sample pattern data XML, ‘WAIST’ is interpreted as 25.93 inches in waist girth with ‘MMP_ID’ that is also used in body scan data descriptions.

**MMP XSD Formation and Validation Test Results**

MMP XSD (02 MMP.xsd) includes all necessary XML schemas for formatting body scan data XML and pattern data XML. Figure 99 shows the validation process of all experimental XML and XSD (XML Schema) developed in Objective 4.

The validation process was divided into an upper and lower level. The upper level is easily recognized by XML users such as [TC]\(^2\) and Gerber Technology, Inc. The lower level is a hidden process for validating XML documentations that have appeared in the upper level (See Figure 99).

*Figure 99. Validation process of XML and schemas between [TC]\(^2\)and Gerber Technology, Inc.*
As shown in Figure 99, in the upper level, a sample pattern data XML and a Body scan data XML are validated with MMP XSD (02 MMP.xsd). In the lower level, MMP XSD was understood by only software programmers at [TC]$^2$ and Gerber Technology, Inc., and body scan data XSD and pattern data XSD were imported from each company’s system into MMP XSD. The validation of MMP XSD (02 MMP.xsd) including body scan data XSD and pattern data XSD was examined with a XMLSpy software program tool. The result is shown in Figure 100.

![MMP XSD formation and validation test result](image)

Figure 100. MMP XSD formation and validation test result

As shown in Figure 100, the XMLSpy test validated the MMP XSD. This proves that both XML in the upper level and XSD in the lower level are applicable. However, practical acceptance of the XML schema is still dependent on users or companies.
Results of XML (eXtensible Markup Language) for Standardization

In this experimental design of body measurement data standardization, the XML format was used for bi-directional interpretation and communication between 3D body scan systems and 2D apparel CAD systems for the following reasons:

- Potential data format for the future,
- Simple custom markup language for standardization,
- Compatibility of data file format,
- And small file size for fast transmission.

**Potential data format for the future.** XML is a potential data format for the future since it has been generally implemented in most businesses. From the related literature review, the XML format was determined to be a significantly useful tool for emerging B-to-B commerce computer language in many industries, including the apparel industry and in standard organizations (Baker, 2002; Chang, 2002; Eshelman, 2000). The ASTM D13.66 subcommittee has discussed implementing the XML data format for developing future standard pattern data exchange formats.

**Simple custom markup language for standardization.** An advantage of the use of XML is that it is an easily readable data description. For example, XYZ coordinates or color values with other file formats, such as DXF, RGB and VRML, have limited ability to describe the data. However, XML can include definitions of the values with tagged data formats since XML (eXtensible Markup Language) is a meta-language that is used to create other markup language.
XML is a custom markup language with tags that are unique to a certain type of data with flexibility in solving data structuring problems. The XML format provides a basic structure and set of rules to which any markup language must adhere (Morrison, 2001). According to Matsumura (1998), key characteristics of XML are structured, self-describing (metadata= data about data), and extensible. XML is an extremely structured language specification. Good XML can be both well-formed and valid (Matsumura, 1998). Unlike most people’s misunderstanding of the XML flexibility, XML includes certain rules and structure. This means that well formed and valid XML is important for standardization.

**Compatible data file.** XML could be used to represent any kind of information and on any computer platform (Morrison, 2001). Table 19 shows the XML data file format compatibility with the following sample data file formats used in this research: XML, database file, [TC]²’s body measurement file, and Gerber pattern data file.

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment format</td>
<td>XML</td>
</tr>
<tr>
<td>Pattern data in Gerber Technology, Inc.</td>
<td>DXF</td>
</tr>
<tr>
<td>Body measurements in [TC]²</td>
<td>ORD</td>
</tr>
<tr>
<td>Database</td>
<td>MDB</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>XML</th>
<th>MDB</th>
<th>HTML</th>
<th>TXT</th>
<th>DOC</th>
<th>XLS</th>
<th>ORD</th>
<th>DXF</th>
</tr>
</thead>
<tbody>
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<td>√</td>
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</table>

As shown in Table 19, the *.DXF file format pattern data from Gerber has the least compatibility with other documentation files. On the other hand, XML had the most compatibility with the other compared documentation files. [TC]²’s *.ORD file
generated from the MEP file that provided customizable body measurement definitions can be read in XML format. The MEP file provided the *.ORD file through the body measurement data batching process after a body scan was processed. Even though the MEP file with the *.ORD file provided flexibility in defining different body measurements, the *.ORD file still had the limitation of transferring data to database.

In addition, the *.ORD data file format could not show data structure in a database. The database could display data structure but it did not have compatibility with *.ORD data file format. XML was created to show data structure with tags and can be transferred to any database as well as to HTML. Compared to a traditional database, XML data is pure text, which means it can be processed and manipulated very easily. The XML document can be opened in a text editor such as Windows Notepad to view or edit the XML code. XML makes it easy to transfer data between one application and another, and across networks since XML is pure text. XML essentially establishes a platform-neutral means of structuring data, which is ideal for networked applications, including Web-based applications.

**Small file size for fast transmission.** The XML file size used in this research Objective 4 was small. Because of the small file size, it was easy and fast to transfer the data through the Internet. The XML file is small enough so that it can be stored on a smart card. Table 20 shows examples of XML format file size for body measurements and ASTM pattern data schema.
As shown in Table 20, the range of file sizes used in this research is from 5 kb to 90 kb. Body scan data XSD (04 Body scan data.xsd) and Body scan data XML (06 Body scan data.xml) have file sizes from 10 to 24 kb to describe data two body measurements from the [TC]²’s scan system. MMP XSD (02 MMP.xsd) and MMP XML (03 MMP.xml) have file sizes from 14 to 35 kb. These files include full descriptions of landmarks and body measurements. The ASTM pattern data schema from Gerber Technology Inc. had the biggest file size of 90 kb but, this is still considered to be a small file size since the file contains all of the information about garment pattern pieces. In these results, the XML format shows significant potential for use in standardization of body measurement data between body scan systems and apparel CAD systems.

**Structure of Data Connectivity with IDEF1X (Objective 5)**

A structure of standardization and integration for the apparel application domain was developed to demonstrate the data connectivity between body scanning systems and CAD systems in Objective 5. An Integration Definition for Information Modeling (IDEF1X) was used for the data connectivity in a database system. Body scan data and pattern data in an XML format were converted to database format to develop a sample database system that supports a concept of standardization and integration of body
measurement data between body scan systems and apparel CAD systems (see Figure 101).

Figure 101. Data conversion from XML to Database

Figure 101 shows the process of data conversion from XML format to database format. A sample body scan data XML file (06 Body scan data.xml) and a sample pattern data XML file (11 Sample pattern data.xml) were successfully converted to database format in this experiment. The converted databases, a body scan data database (08 Body scan database.mdb) and a pattern data database (12 Testing pattern data.mdb), were imported into the MMP database (MMP.mdb) to develop a sample standardization database system (13 Sample standardization model.mdb). An IDEF1X model with the sample database system is introduced in this Objective 5.

**IDEF1X Model for Connectivity Body Scan Data and Pattern Data**

An IDEF1X model of the database system (13 Sample standardization model.mdb) was created to provide an integrating data structure for apparel application domains, and to clarify the MMP identification (MMP_ID) for bi-directional interpretation between body scan data and pattern data. A sample standardization database (13 Sample standardization model.mdb) contained body scan data, pattern data, and body measurement definitions. The IDEF1X model was created by analyzing data
relationships in the sample database. Figure 102 shows the IDEF1X of MMP ID references in the sample database.

![Diagram](image)

**Figure 102.** IDEF1X of MMP_ID references

In Figure 102, Foreign Key (FK) means a migrated attribute whose values match in the Primary Key of a related root element. A Foreign Key results from the migration of a main element Primary Key through a specific connection and categorization relationship. A Primary Key is the unique identifier of an entity. A specific connection relationship is depicted as a line drawn between the main entity and the sub entity with a dot at the sub entity end of the line. The default sub entity cardinality is zero, one or many (one-to-many relationship). For example, ‘Body_Code’ in the main entity (‘BodyPart’) migrates to the sub entity (‘Landmarks’) identifying a dependency with one-to-many relationship.
In Figure 102, ‘Landmark_ID’ in the main entity (‘Landmarks’) migrates to the sub entity (‘MMP_List’) identifying a dependency. ‘MMP_ID’ is a Primary Key of an ‘MMP_List’ entity, and it is migrated into entities, ‘ISO8559’ and ‘ASTM5219’. Each entity shows data connectivity by identifying relationships. Figure 103 shows body scan data and pattern data relationships in the IDEFX model.

![Diagram](image)

**Figure 103.** Body scan data and pattern data in IDEFX
As shown in Figure 103, ‘MMP_ID’, a unique identifier of the entity
(‘MMP_List’), is very important for standardization and integration because the
‘MMP_ID’ is a Primary Key and is migrated into entities that contain body scan data or
pattern data. The main entity (‘MMP_List’) includes body measurement descriptions,
landmark identifications, and body measurement identifications with ‘MMP_ID’. Body
scan data and pattern data are connected with the identifier (‘MMP_ID’).

The Body scan data has 4 entities: ‘Scan_Company’, ‘Scan_Landmark’,
‘Scan_List’, and ‘Measurements’. Entities have their unique identifier for each entity.
For example, ‘Scan_ID’, a Primary Key of the entity (‘Measurements’) is required for
identification of a scanned object, and migrates into other entities (‘Scan_List’ and
‘Scan_Landmark’). A ‘MMP_ID’ in the ‘Measurements’ entity is migrated from the
‘MMP_List’ entity.

The ‘MMP_ID’ is also found in pattern data. For example, ‘Size_Table’ and
‘Alterations’ in pattern data have the ‘MMP_ID’ as a Foreign Key from the MMP list
entity. These two entities are related to body measurement data for alteration or size
selections. The ‘Alt_Rule_Name’ in these entities contains body measurements defined
by users. This user defining causes problems with identifying where to apply alterations,
and matching body measurement data in the body scan system and sizes in the CAD. At
this point, ‘MMP_ID’ has an important rule of connectivity between body scan data and
pattern data. In this result, the IDEF1X model shows the connectivity between body scan
data and pattern data (See Figure 104).
Figure 104. IDEF1X model of data connectivity for standardization and integration for apparel applications
Figure 104 shows a final IDEF1X model of data connectivity for standardization and integration for apparel applications, adding customer information and three image files of body scan figure images, basic pattern images, and alteration pattern images. This IDEF1X model shows how to connect body scan data and pattern data for apparel applications. In Figure 104, an entity of the customer information consists of a Primary Key of customer identification (Customer ID) and follows Foreign Keys to find customer information in other entities: ‘Scan_ID’ (identification of measurements); ‘Scanner’ (identification of scanner); ‘Vendor Name’ (identification of CAD company); ‘StyleName’ (identification of style name that has been used in a customer’s pattern); ‘SizeName’ (identification of size name), ‘SizeId’ (identification of size), ‘Alt_Table’ (identification of alteration table); and ‘PieceName’ (identification of piece name that has been used in a customer’s pattern).

These migrated keys of each entity make more connections to the pattern information than the previous model shown in Figure 104. For example, ‘PatternDataDetails’, ‘PatternData’, ‘GradingData’, and ‘Pieces’ were included in this IDEF1X model by adding this ‘00_Customers’ entity. In addition, body scan measurement data is related to the pattern information through the entity ‘00_Customer’s entity’.

Figure 104 shows an identifying dependency relationship. The sub entity is an identifier dependent represented by a rounded corner box, and the Primary Key attribute of the main entity are also migrated Primary Key attributes of the sub entity. For example, entities of three image files consist of a Primary Key attribute of each image.
entity (‘MMP_ID’), figures, and Foreign Keys related to the figures. The Primary Key of each image entity (‘MMP_ID’) is migrated from the main entity (‘MMP_List’). An entity of alteration pattern images (‘03_Alteration_Picture’) is an identifier dependent entity that has a Primary Key attribute (‘MMP_ID’) of the main entity (‘MMP_List’).

In this result, IDEF1X is suggested for structure of the standardization and integration for the apparel application domains required connectivity with body measurement data. According to this final suggested IDEF1X model, a sample application database system has been developed and demonstrates the connectivity of body measurement information between apparel CAD data and body scan data.

**Application Database System Example for Pattern Alteration References**

This application database system example of the body scan data standardization for apparel applications contains a concept of MMP_ID, reference to body scan data for pattern makers, and customer information for alteration (see Figure 105).

![Body Scan Data Standardization for Apparel Applications](image)

**Figure 105.** The main screen in a database system example of the body scan data standardization for apparel applications
Figure 105 shows the main screen to start the application database system example. The concept of MMP_ID is added in this database example to clarify MMP_ID. Body scan data for pattern makers contains body measurement references including body scan data figures and basic pattern figures. Customer information for alterations contains customer information to alter customer’s specified garment pattern pieces. The following Figure 106 shows a MMP example for standardization of body measurements.

![Concept of MMP (Metaphor Matching Process) for Standardization of Body Measurements](image)

**Figure 106.** Concept of MMP for standardization

As shown in Figure 106, this consists of three stages:

- Input user definition or terminology for body measurements.
- Match a user’s body measurements to individual codes for body sections, category of body measurements, and specified body locations.
A user’s body measurement will be shown with a specified identification, called MMP_ID.

As shown in Figure 106, ‘Waist’ is typed into first column, it will appear automatically in the third column. A user selects the closest concept of body measurement by pulling down the dialogue box that contains specified codes with general terms (e.g. WS = Waist, g = Girth, x = Not applicable). The row source of Category, Location1, 2, and 3 are from each entity in the database, and Body_Code included Body_Part so that users can see body measurement terminology (SELECT Body_Part.Body_Code, Body_Part.Terms). As a user selects each concept in the dialogue boxes, it will be saved and opened automatically into the third column to complete the Metaphor Matching Process. The following Figure 107 shows an example of a body reference that includes body scan data figures and pattern figures.

![Reference of BodyScanData for Pattern Makers](image)

**Figure 107.** Body scan data reference for pattern makers

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In Figure 107, this reference to body scan data connects idea of accurate body measurement location, and shows how to actually relate a specific body measurement to the pattern piece. As shown in Figure 107, the data connectivity is possible with common identification of body and pattern data (MMP_ID). Additional definitions are available in this database as a reference. This interface for pattern makers with the reference tools available is easy to find body measurement references. Figure 108 shows a sample of customer information for pattern alteration. Customer information includes scanned information and pattern information for the specified customer.

![Customer Information and Body Measurements](image)

**Figure 108.** Customer information and body measurements

As shown in Figure 108, the scanned information shows a customer’s scan ID (e.g. Female_001), size (e.g. MISSY_DRESS, 2) and measurements. The measurements are controlled by a command button. As a customer clicks the “Measurements” command button, a body measurements table will pop up to show a specified customer’s measurements. The “Measurements” command button executes the following event
procedures. The event procedures allow finding a specific measurement record by matching customer’s scan ID.

Private Sub Customer_Measurements_Click()
On Error GoTo Err_Customer_Measurements_Click

    Dim stDocName As String
    Dim stLinkCriteria As String

    stDocName = "Measurements"
    stLinkCriteria = "[Scan_ID]=" & "" & Me![Scan_ID] & ""
    DoCmd.Close
    DoCmd.OpenForm stDocName, , , stLinkCriteria

Exit_Customer_Measurements_Click:
    Exit Sub

Err_Customer_Measurements_Click:
    MsgBox Err.Description
    Resume Exit_Customer_Measurements_Click

End Sub

As shown in Figure 108, pattern information includes style name (e.g. DRESS), piece name (e.g. SQSHIFTBK), and alteration (e.g. ALTERMISSYCRESDARTS). Style name and piece name could be used for finding detail pattern piece information. Detail alteration information can be shown by clicking an “Alteration” command button (e.g. Go To Alteration). The “Alteration” command button has following event procedures.

Private Sub Com_Find_Alt_Click()
On Error GoTo Err_Com_Find_Alt_Click

    Dim stDocName As String
    Dim stLinkCriteria As String

    stDocName = "03_Alteration_Pictures"
    stLinkCriteria = "[Alt_Table]=" & "" & Me![Alt_Table] & ""

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DoCmd.Close
DoCmd.OpenForm stDocName, , stLinkCriteria

Exit_Com_Find_Alt_Click:
Exit Sub

Err_Com_Find_Alt_Click:
MsgBox Err.Description
Resume Exit_Com_Find_Alt_Click

End Sub

As shown in this event procedure, alteration table name (e.g. [Alt_Table]) was the criteria to link to the alteration table. This results in filtering the alteration information by matching it to the alteration table name (e.g. ALTERMISSYCREDARTS). The alteration information includes alteration rule name, MMP_ID, and descriptions (See Figure 109).

Figure 109. Pattern Alterations
In Figure 109, a pattern alteration rule area has a description of alteration method and MMP_ID. The MMP_ID is used to link MMP reference, shown in Figure 107. For example, alteration rule name (e.g. WAIST) tells a pattern alteration part that it has to be fit in specific body area. The MMP reference will be shown by clicking the command button (e.g. MMP Reference). The MMP reference command button has following event procedures to show body measurement reference.

Private Sub ComAlterToRef_Click()
On Error GoTo Err_ComAlterToRef_Click

    Dim stDocName As String
    Dim stLinkCriteria As String

    stDocName = "MMP reference"
    stLinkCriteria = "[MMP_List_MMP_ID]=" & "" & Me![MMP_ID] & ""
    DoCmd.Close
    DoCmd.OpenForm stDocName, , , stLinkCriteria

Exit_ComAlterToRef_Click:
    Exit Sub

Err_ComAlterToRef_Click:
    MsgBox Err.Description
    Resume Exit_ComAlterToRef_Click

End Sub

As shown in this event procedure, MMP_ID was the criteria area to link to the reference table (e.g. stLinkCriteria = "[MMP_List_MMP_ID]=" & "" & Me![MMP_ID] & """). Filtered information using this event procedure is shown in Figure 108 for reference of body measurement data. This research has resulted in a database system with identification codes to demonstrate the connectivity between a body scan system and an apparel pattern CAD system. The MMP, XML schema and a database system example
prove that standardization and integration are possible using simple and common identification codes. In addition, this database application with data connectivity will be a useful reference for pattern makers, students, and body scan developers.
CHAPTER VIII

CONCLUSIONS AND SUGGESTIONS

Apparel CAD/CAM companies are attempting to link 3D body scan systems with their existing apparel CAD products for made-to-measure and mass customized garments. The 3D body scan systems have unrealized potential use for apparel applications because body scan systems can provide accurate and consistent body measurement data to apparel pattern makers using apparel CAD systems. According to the survey of body scan systems, body scan systems have shown the potential for connectivity with apparel CAD systems.

Body scan data for apparel applications referred to current body measurement standards such as ASTM, ISO. According to the investigation of current body measurement standards, the body measurement standards have shown inaccuracy and inconsistency in describing body measurements. A Metaphor Matching Process (MMP) was used to develop a set of Identification Codes to illustrate how body measurement terminology can be standardized.

The set of Identification Codes represented specific body measurements, providing semantics and syntax for both 3D body scanning systems and apparel CAD systems. Instead of long verbal descriptions of body measurements, the set of Identification Codes simplifies the long descriptions by employing a coding system to exactly define body measurement definitions. As a result, the effectiveness of matching body measurements with a set of Identification Codes was proven with SQL (comparison with current body measurement standards).
Body scan developers commonly mentioned the DXF file format as a possible exchange data format with apparel CAD systems because they thought DXF was an applicable apparel CAD data file format. A specific AAMA DXF file format has been used for apparel CAD systems, but still it is not a proven standard data format between apparel CAD systems and body scan systems. In a standards organization for exchanging apparel CAD pattern data, instead of DXF format, XML format is being considered as the future standard data format. For instance, E-cluster has used XML in its research project of sizing in U.K.

With this trend of using XML format for the future, an exchange data file format in XML (MMP XML with XSD) was developed for achieving standardization of the body measurement terminology for bi-directional interpretation and transmission of data generated by 3D body scanning systems and 2D CAD pattern generation systems in this research. In addition, a logical IDEF1X model of the data flow structure demonstrated the connectivity between a 3D body scanning system and an apparel CAD system. The result indicates that a set of Identification Codes had an important role in facilitating connectivity between body scan systems and apparel CAD systems.

In this dissertation, the MMP XML format is distinguished from E-Cluster’s XML format in that MMP XML with Identification codes was a central control source for bi-directional interpretation and transmission of data. In addition, XML format was found to be important for standardization providing several advantages.

First, XML format provides easily readable data descriptions with a simple custom markup language. For instance, in this research, while DXF had a limitation in
describing the data value, XML format could include definitions with tagged data format. It allowed both apparel CAD developers and body scan developers to clearly understand body measurement data descriptions. Second, XML format is a compatible data file. For instance, body measurement data in XML format (MMP XML) was easily converted into other data formats used in body scan systems and CAD systems such as ORD, MDB, TXT, and XLS. This conversion made possible bi-directional interpretation of body measurement data between [TC]2 and Gerber Technology, Inc. Third, data in XML format (MMP XML) was efficiently transferred via the Internet because of the small file size.

Regardless of the advantages of XML format, the following limitations of using the XML format were found in the current application. First, few people had began writing the XML format in both body scan companies and apparel CAD companies. Even though developers and researchers realize the importance of using the XML format for standardization, currently, it was difficult to find programmers who could actually write in XML format. Second, existing systems had limitations in character number and types for describing XML format data. For instance, body measurements in the [TC]2 system and size tables in the Gerber management system had a character number limit for describing body measurements. Body measurement data in the XML format could not be directly represented in existing systems. Third, the acceptance of XML schema by any other companies was not guaranteed because the schema was a suggestion, not an obligation. In this research, validation was accomplished by examining XML schema between Gerber Technology, Inc. and [TC]2, but XML schema must be accepted by both
body scan system developers and apparel CAD/CAM system developers for integration between technologies to be realized. These findings indicate that acceptance of the XML format is tightly related to timely agreements in the apparel industry.

In this research, a database system example was converted from XML format data that was gathered from an apparel CAD system and a body scan system. The database system example successfully demonstrated connectivity between apparel CAD pattern and body scan data for standardization and integration, providing a logical IDEF1X model of the data flow structure between a 3D body scanning system and a CAD system in apparel design. In addition, this connectivity demonstration with user interface could be useful for pattern makers, apparel body scan developers, and students.

The approach outlined in this study should be replicated in further studies, and the following research directions are suggested:

1. Further studies should be done to demonstrate integration of data among other CAD/CAM suppliers and virtual design suppliers.

2. The Methodology of Metaphor Matching Process with Identification Codes should be adopted for standardization and integration in the apparel industry. Hence, data could be efficiently exchanged in any stage of manufacturing or altering garments for mass customization.

3. Validation of the schema should be provided through a standards organization to be determined as a standard data format.

4. A standard should be fixed and practically adopted in the apparel industry.
5. The approach with XML data format should be replicated in apparel manufacturing and retailing systems. Hence, the exchange of technical information could be moved forward to the retailer who facilitates consumer purchase. Since XML allows us to build interfaces that remove the communication barriers, it can be applied to implement quick response by designing a system of efficient information interchange with emphasis on data flow while acknowledging both the apparel manufacturer's and customer’s needs.
REFERENCES


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Wright, S. (Jul 2000). Mass customization could be the key to getting our industry back on track. Apparel Industry Magazine 61 (7), 104.

Young, R. E. (2000). Notes on information flow modeling using IDEF0. Department of Industrial Engineering, North Carolina State University, Raleigh, NC.


# APPENDICES

## Appendix A. \([TC^2]\) Parameters of Describing Semantic

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Methods /points</th>
<th>Descriptions</th>
<th>Applied areas (semantics)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waist</td>
<td>Center Back Point</td>
<td>Starting height for center back point</td>
<td>Waist</td>
</tr>
<tr>
<td></td>
<td></td>
<td>upper limit of center back point height referenced to small of back: ( ) inches</td>
<td>Hips</td>
</tr>
<tr>
<td></td>
<td></td>
<td>lower limit of center point height referenced to small of back: ( ) inches</td>
<td>Abdomen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Formula 1 (Option) Starting height = crotch height + ( )* hip circumference + ( )* hip circumference squared</td>
<td>Outseam</td>
</tr>
<tr>
<td>Center Front Point</td>
<td>Upper limit of center front point height referenced to center back point: ( ) inches</td>
<td>Vertical Rise</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>lower limit of center front point height referenced to center back point: ( ) inches</td>
<td>Crotch Length</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Front center point is at a fixed from the center back point (Option) Angle in degrees from horizontal that center front point is from center back point (- is above, + is below)</td>
<td>Neck to Waist</td>
</tr>
<tr>
<td>Side Points</td>
<td></td>
<td>Amount the side points are allowed to go above a line between the center back point and the center front point: inches</td>
<td>Shoulder to Waist</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amount the side points are allowed to go below a line between the center back point and the center front point: inches</td>
<td>Stomach</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amount the side points are allowed to vary in height from each other: ( ) inches</td>
<td>Bust to Waist</td>
</tr>
<tr>
<td>Seat</td>
<td>Methods</td>
<td>Furthest protrusion to the rear / Widest from side to side (Selections) Use &quot;Hips&quot; to find largest circumference</td>
<td>Seat</td>
</tr>
<tr>
<td>parameters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thigh</td>
<td>Find a fixed location (Selection) Fixed location Start at this percentage of distance from floor to crotch: ( ) % Add this distance to the starting point: ( ) inches</td>
<td>Thigh</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Find largest between limits (Selection) Upper limit Start at this percentage of distance from floor to crotch: ( ) % Add this distance to the starting point: ( ) inches</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower limit Use a knee parameters for lower limit (Selection) Start at this percentage of distance from floor to crotch: ( ) % Add this distance to the starting point: ( ) inches</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee</td>
<td>Methods</td>
<td>Start at this percentage of distance from floor to crotch: ( ) % Add this distance to the starting point: ( ) inches</td>
<td>Knee</td>
</tr>
<tr>
<td>Parameters</td>
<td>Methods / points</td>
<td>Descriptions</td>
<td>Applied areas (semantics)</td>
</tr>
<tr>
<td>---------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>Inseam</td>
<td>Inseam measured methods start at the crotch point.</td>
<td>Straight down/ to inside of foot (Selection)</td>
<td>Inseam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Distance above floor to stop the measurement. Positive numbers are above floor, negative numbers are below floor: ( ) inches  Set all existing inseam and outseam distance to this value (Option)</td>
<td></td>
</tr>
<tr>
<td>Neck to</td>
<td>Wings</td>
<td>Measure between blades [Wings In] / Measure over blades [Wings Out] (Selections)</td>
<td>Neck to Blades</td>
</tr>
<tr>
<td>Shoulder blade</td>
<td>Methods</td>
<td>To prominent of shoulder blade / Fixed distance below neck point distance: ( ) inches (Selections)</td>
<td></td>
</tr>
<tr>
<td>Shoulder</td>
<td>Methods</td>
<td>At a specified slop from the armpits / When the drop off reaches a fixed slop : Slop ( / )/100 (Selections)</td>
<td>Shoulder</td>
</tr>
<tr>
<td>parameters</td>
<td></td>
<td>this is a actually the reciprocal of the slope. A slope of 0 is vertical and you can not enter a number big enough to reach horizontal. A slope of 100 is equivalent to 45 degrees.</td>
<td>Shoulder to Shoulder</td>
</tr>
<tr>
<td>Overarm</td>
<td>Select starting height</td>
<td>At average height of armpits /Percentage of way from bust to shoulder / At average height of biceps (Selections)</td>
<td>Over Arm</td>
</tr>
<tr>
<td>Parameters</td>
<td>Select starting point you want to use to find the chest</td>
<td>Start at a fixed distance from the armpit (Selection)</td>
<td>Chest</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use highest armpit/ average armpit/ lowest armpit (selection)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Allow to go above bust in front / Force to go over shoulder blades in back / Force to go under armpits (Options)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>from the bust (Selection)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Distance from starting point ( ) inches</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>from the bust/ from the shoulder blades (Selection)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use a negative number to start below the armpit or bust. Use a positive number to start above</td>
<td></td>
</tr>
<tr>
<td>Coat sleeve</td>
<td>Insleeve</td>
<td>Armpit to wrist/ Shoulder point to wrist (Selection)</td>
<td>Coat Sleeve</td>
</tr>
<tr>
<td>parameters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outsleeve</td>
<td>Back of neck - over shoulder to wrist. Same as shirt sleeve except to wrist instead of knuckle. / Middle of back -over shoulder to wrist. Choose the angle from shoulder points. Angle from shoulder point ( ) degree (Selections)</td>
<td></td>
</tr>
<tr>
<td>Shirt sleeve</td>
<td>Method</td>
<td>Back of neck - over shoulder to wrist / Back of neck - over shoulder to knuckle minus constant distance. Distance above knuckle ( ) inches (Selection)</td>
<td>Shirt Sleeve</td>
</tr>
<tr>
<td>parameters</td>
<td>Methods</td>
<td>Min drop in back ( ) inches</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max drop in back ( ) inches</td>
<td></td>
</tr>
<tr>
<td>Bust</td>
<td>Methods</td>
<td>Use a horizontal plane / shortest path method / a plane fitted to the shortest path ( selections)</td>
<td>Bust</td>
</tr>
<tr>
<td>parameters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underbust</td>
<td>Methods</td>
<td></td>
<td>Underbust</td>
</tr>
</tbody>
</table>
Appendix B. MMP Schema (02 MMP.xsd)

```xml
<?xml version="1.0" encoding="UTF-8"?>
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema">
  <xs:import schemaLocation="C:\Dissertation (SU XML)\MMP_XML\MMPDB_XML\04 Body scan data.xsd"/>
  <xs:import schemaLocation="C:\Dissertation (SU XML)\MMP_XML\MMPDB_XML\10 Pattern data.xsd"/>
  <xs:element name="ASTM5219">
    <xs:annotation>
      <xs:documentation>One of body measurement standards in ASTM</xs:documentation>
    </xs:annotation>
    <xs:complexType>
      <xs:sequence>
        <xs:element name="Terms">
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            <xs:restriction base="xs:string">
              <xs:maxLength value="50"/>
            </xs:restriction>
          </xs:simpleType>
        </xs:element>
        <xs:element name="MMP_Term">
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            </xs:restriction>
          </xs:simpleType>
        </xs:element>
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              <xs:maxLength value="60"/>
            </xs:restriction>
          </xs:simpleType>
        </xs:element>
        <xs:element name="Landmark_ID">
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            <xs:restriction base="xs:string">
              <xs:maxLength value="50"/>
            </xs:restriction>
          </xs:simpleType>
        </xs:element>
        <xs:element name="Description">
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              <xs:maxLength value="65534"/>
            </xs:restriction>
          </xs:simpleType>
        </xs:element>
      </xs:sequence>
    </xs:complexType>
  </xs:element>
  <xs:element name="Body_Part">
    <xs:annotation>
      <xs:documentation>List of MMP Body code that used in MMP_ID</xs:documentation>
    </xs:annotation>
    <xs:complexType>
      <xs:sequence>
        <xs:element name="Body_Code">
          <xs:annotation>
            <xs:documentation>Body Part number for Anthropometric Measurement</xs:documentation>
          </xs:annotation>
        </xs:element>
      </xs:sequence>
    </xs:complexType>
  </xs:element>
</xs:schema>
```
<xs:simpleType>
    <xs:restriction base="xs:string">
        <xs:maxLength value="5"/>
    </xs:restriction>
</xs:simpleType>

<xs:element name="Terms">
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            <xs:maxLength value="30"/>
        </xs:restriction>
    </xs:simpleType>
</xs:element>

<xs:element ref="Landmarks" minOccurs="0" maxOccurs="unbounded"/>

<xs:sequence/>

<xs:complexType>
    <xs:key name="Body_Part_Body_Code">
        <xs:selector xpath=""/>
        <xs:field xpath="Body_Code"/>
    </xs:key>
</xs:element>

<xs:element name="Category">
    <xs:annotation>
        <xs:documentation>List of category codes that used in MMP_ID</xs:documentation>
    </xs:annotation>
    <xs:complexType>
        <xs:sequence>
            <xs:element name="Code">
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                        <xs:maxLength value="50"/>
                    </xs:restriction>
                </xs:simpleType>
            </xs:element>
            <xs:element name="Category">
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                    <xs:restriction base="xs:string">
                        <xs:maxLength value="50"/>
                    </xs:restriction>
                </xs:simpleType>
            </xs:element>
        </xs:sequence>
    </xs:complexType>
</xs:element>

<xs:element name="Direction">
    <xs:annotation>
        <xs:documentation>Point or level moving direction</xs:documentation>
    </xs:annotation>
    <xs:complexType>
        <xs:sequence>
            <xs:element name="Code">
                <xs:simpleType>
                    <xs:restriction base="xs:string">
                        <xs:maxLength value="50"/>
                    </xs:restriction>
                </xs:simpleType>
            </xs:element>
            <xs:element name="Direction">
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  </xs:element>
  </xs:sequence>
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</xs:element>

<xs:element name="MMP_ID">
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  </xs:simpleType>
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<xs:element>
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<xs:keyref name="ISO8559_MMP_ID" refer="MMP_List_MMP_ID">
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  <xs:field xpath="MMP_ID"/>
</xs:keyref>
</xs:element>

<xs:element name="Landmarks">
  </xs:annotation>
<xs:element>
  <xs:element name="Link_code">
    <xs:annotation>
      <xs:documentation>Link body points or landmarks to describing girth, length, or width. e.g. _ to, ~between.</xs:documentation>
    </xs:annotation>
    <xs:complexType>
      <xs:sequence>
        <xs:element name="Code">
          <xs:simpleType>
            <xs:restriction base="xs:string">
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    </xs:complexType>
  </xs:element>
</xs:element>

<xs:element name="Location1">
  <xs:annotation>
    <xs:documentation>Location of torso or legs. Select from only front, back, or side.</xs:documentation>
  </xs:annotation>
  <xs:complexType>
    <xs:sequence>
      <xs:element name="Code">
        <xs:simpleType>
          <xs:restriction base="xs:string">
            <xs:maxLength value="50"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
      <xs:element name="Location_1">
        <xs:simpleType>
          <xs:restriction base="xs:string">
            <xs:maxLength value="50"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
    </xs:sequence>
  </xs:complexType>
</xs:element>

<xs:element name="Location2">
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        </xs:simpleType>
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      <xs:element name="Location_2">
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</xs:complexType>
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  <xs:annotation>
    <xs:documentation>List of MMP ID and terms</xs:documentation>
  </xs:annotation>
  <xs:complexType>
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        </xs:simpleType>
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</xs:element>
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</xs:element>
</xs:complexType>
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</xs:complexType>
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<xs:element name="Description">
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        <xs:restriction base="xs:string">
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    <xs:element ref="ASTM5219" minOccurs="0" maxOccurs="unbounded"/>
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<xs:element name="Unit">
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        <xs:documentation> Unit of detail amount.</xs:documentation>
    </xs:annotation>
    <xs:complexType>
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    </xs:annotation>
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Appendix C. MMP XML (02 MMP.xml)

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  <Body_Part>
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    <Terms>Bust</Terms>
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  <Body_Part>
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    <Terms>Break</Terms>
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  <Body_Part>
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    <Terms>Cross back</Terms>
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  <Terms>Neck (Neck Base)</Terms>
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</Landmarks>
</Landmark_ID>AKps21</Landmark_ID>
<Terms>Ankle right side left point</Terms>
</Body_Code>AK</Body_Code>
</Description>The joint with inside left ankle bone between the foot and lower leg.</Description>
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</Landmark_ID>FTps11</Landmark_ID>
<Terms>Foot left side left point</Terms>
</Body_Code>FT</Body_Code>
</Description>Outside point of the left side foot.</Description>
</Landmarks>
</Landmark_ID>FTps12</Landmark_ID>
<Terms>Foot left side right point</Terms>
</Body_Code>FT</Body_Code>
</Description>Inside point of the left side foot.</Description>
</Landmarks>
</Landmark_ID>FTps21</Landmark_ID>
<Terms>Foot right side left point</Terms>
</Body_Code>FT</Body_Code>
</Description>Inside point of the left side foot.</Description>
</Landmarks>
</Landmark_ID>FTps22</Landmark_ID>
<Terms>Foot right side right point</Terms>
</Body_Code>FT</Body_Code>
</Description>Outside point of the left side foot.</Description>
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<Terms>Head point</Terms>
</Body_Code>HD</Body_Code>
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</Landmark_ID>FLps22</Landmark_ID>
<Terms>Floor right</Terms>
</Body_Code>FL</Body_Code>
</Description>The sole of the right foot. [ X,Y,Z = X,0,0]</Description>
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</Landmark_ID>SDpsx2</Landmark_ID>
<Terms>Shoulder right point</Terms>
</Body_Code>SD</Body_Code>
</Description>The point on the top of the right shoulder joint between the upper arm and the shoulder blade.</Description>
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</Landmark_ID>BUpfx2</Landmark_ID>
<Terms>Bust right point</Terms>
</Body_Code>BU</Body_Code>
<Description>The location of the apex of the right bust along the horizontal line at the fullest point of the bust or chest.</Description>

</Landmarks>

</Landmarks>

<Landmark_ID>APpsx2</Landmark_ID>
<Terms>Armpit right point</Terms>
<Body_Code>AP</Body_Code>
<Description>(On the right side imaginary line) The location at the center of the body in the hollow under the junction of the right arm and the shoulder.</Description>

</Landmarks>

</Landmarks>

<Landmark_ID>BRpfx2</Landmark_ID>
<Terms>Break point right front</Terms>
<Body_Code>FB</Body_Code>
<Description>The location on the front of the body where the right arm separates from the body.</Description>

</Landmarks>

</Landmarks>

<Landmark_ID>NKpx0</Landmark_ID>
<Terms>Neck center front point</Terms>
<Body_Code>NK</Body_Code>
<Description>The prominent point of the seventh cervical vertebra at the back of the body.</Description>

</Landmarks>

</Landmarks>

<Landmark_ID>NKpfx0</Landmark_ID>
<Terms>Neck center front point</Terms>
<Body_Code>NK</Body_Code>
<Description>The hollow "pit of the neck" located between the clavicles (collar bones) at the base of the front neck.</Description>

</Landmarks>

</Landmarks>

<Landmark_ID>SNpsx2</Landmark_ID>
<Terms>Shoulder neck right point</Terms>
<Body_Code>SN</Body_Code>
<Description>The point where the top of right shoulder meets the neck at the base of the side of the neck.</Description>

</Landmarks>

</Landmarks>

<Landmark_ID>WSpfx0</Landmark_ID>
<Terms>Waist center front point</Terms>
<Body_Code>WS</Body_Code>
<Description>The point on the horizontal line at the natural waist, which is the narrowest point around the torso, below the bottom rib and above the hip bones at the front of the body.</Description>

</Landmarks>

</Landmarks>

<Landmark_ID>WSpfx0</Landmark_ID>
<Terms>Waist center back point</Terms>
<Body_Code>WS</Body_Code>
<Description>The point on the horizontal line at the natural waist, which is the narrowest point around the torso, below the bottom rib and above the hip bones at the back of the body.</Description>

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</Landmarks>

<Landmark_ID>WSpsx2</Landmark_ID>
<Terms>Waist right side point</Terms>
<Body_Code>WS</Body_Code>
<Description>(On the right side imaginary line) The right side point on the horizontal line at the natural waist, which is the narrowest point around the torso, below the bottom rib and above the hip bones. </Description>

<Landmarks>
    <Landmark_ID>HPpx0</Landmark_ID>
    <Terms>Hip center front point</Terms>
    <Body_Code>HP</Body_Code>
    <Description>A point at the hip at the horizontal level, across the fullest part of the buttocks and over the upper end of the thigh bone. Perpendicular the horizontal level line to the center front of the body. </Description>
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<Landmarks>
    <Landmark_ID>HPpx0</Landmark_ID>
    <Terms>Hip center back point</Terms>
    <Body_Code>HP</Body_Code>
    <Description>A point at the hip at the horizontal level, across the fullest part of the buttocks and over the upper end of the thigh bone. Perpendicular the horizontal level line to the center back of the body. </Description>
</Landmarks>

<Landmarks>
    <Landmark_ID>HPpx2</Landmark_ID>
    <Terms>Hip right side point</Terms>
    <Body_Code>HP</Body_Code>
    <Description>(On the right side imaginary line) A point at the right side hip at the horizontal level, across the fullest part of the buttocks and over the upper end of the thigh bone. </Description>
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<Landmarks>
    <Landmark_ID>AKos22</Landmark_ID>
    <Terms>Ankle right side right point</Terms>
    <Body_Code>AK</Body_Code>
    <Description>The joint with right ankle bone between the foot and lower leg. </Description>
</Landmarks>

<Landmarks>
    <Landmark_ID>KNpf20</Landmark_ID>
    <Terms>Knee right point</Terms>
    <Body_Code>KN</Body_Code>
    <Description>The point on the front of the knee halfway between the top and bottom of the right knee cap. </Description>
</Landmarks>

<Landmarks>
    <Landmark_ID>ELpb20</Landmark_ID>
    <Terms>Right elbow point</Terms>
    <Body_Code>EL</Body_Code>
    <Description>The line perpendicular to the length of the arm located at the joint which articulates between the right upper arm and the lower arm. </Description>
</Landmarks>

<Landmarks>
    <Landmark_ID>WRpx11</Landmark_ID>
    <Terms>Wrist left point</Terms>
    <Body_Code>WR</Body_Code>
    <Description>A point of the prominent bone on the outside of the left forearm. </Description>
</Landmarks>

<Landmarks>
    <Landmark_ID>CRpx0</Landmark_ID>
    <Terms>Crotch point</Terms>
    <Body_Code>CR</Body_Code>
    <Description>The base of the torso at its center point between the legs. [X, Y, Z = 0, Y, 0] </Description>
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<Landmarks>
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    <Terms>Side imaginary line right(Side Seam)</Terms>
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  <Landmark_ID>AKps11</Landmark_ID>
  <Terms>Ankle left side left point</Terms>
  <Body_Code>AK</Body_Code>
  <Description>The joint with left ankle bone between the foot and lower leg.</Description>
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<Landmarks>
  <Landmark_ID>HPpsx1</Landmark_ID>
  <Terms>Hip left side point</Terms>
  <Body_Code>HP</Body_Code>
  <Description>(On the left side imaginary line) A point of the left side hip at the horizontal level, across the fullest part of the buttocks and over the upper end of the thigh bone.</Description>
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<Landmarks>
  <Landmark_ID>APpsx1</Landmark_ID>
  <Terms>Armpit left point</Terms>
  <Body_Code>AP</Body_Code>
  <Description>(On the left side imaginary line) The location at the center of the body in the hollow under the junction of the left arm and the shoulder.</Description>
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<Landmarks>
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  <Terms>Break point left back</Terms>
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  <Description>(On the left side imaginary line) The location on the back of the body where the left arm separates from the body.</Description>
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<Landmarks>
  <Landmark_ID>BUpfx1</Landmark_ID>
  <Terms>Bust left point</Terms>
  <Body_Code>BU</Body_Code>
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<Landmarks>
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  <Terms>Elbow left point</Terms>
  <Body_Code>EL</Body_Code>
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<Landmarks>
  <Landmark_ID>BRpfx1</Landmark_ID>
  <Terms>Break point left front</Terms>
  <Body_Code>FB</Body_Code>
  <Description>The location on the front of the body where the left arm separates from the body.</Description>
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<Landmarks>
  <Landmark_ID>KNpf10</Landmark_ID>
  <Terms>Knee left point</Terms>
  <Body_Code>KN</Body_Code>
  <Description>The point on the front of the knee halfway between the top and bottom of the left knee cap.</Description>
</Landmarks>

<Landmarks>
  <Landmark_ID>SDpsx1</Landmark_ID>
  <Terms>Shoulder left point</Terms>
  <Body_Code>SD</Body_Code>
  <Description>The point on the top of the left shoulder joint between the upper arm and the shoulder blade.</Description>
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<Landmarks/>

<Landmarks>
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<Landmarks>
  <Landmark_ID>SNpxs1</Landmark_ID>
  <Terms>Shoulder neck left point</Terms>
  <Body_Code>SN</Body_Code>
  <Description>The point where the top of left shoulder meets the neck at the base of the side of the neck</Description>
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<Landmarks>
  <Landmark_ID>FLpxx0</Landmark_ID>
  <Terms>Floor center</Terms>
  <Body_Code>FL</Body_Code>
  <Description>The soles of the center feet. [X,Y,Z = 0,0,0]</Description>
</Landmarks>

<Landmarks>
  <Landmark_ID>FLpxs1</Landmark_ID>
  <Terms>Floor left</Terms>
  <Body_Code>FL</Body_Code>
  <Description>The sole of the left foot. [X,Y,Z = -X,0,0]</Description>
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<Landmarks>
  <Landmark_ID>WRpx22</Landmark_ID>
  <Terms>Wrist right point</Terms>
  <Body_Code>WR</Body_Code>
  <Description>A point of the prominent bone on the outside of the left forearm</Description>
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<Landmarks>
  <Landmark_ID>WSpxs1</Landmark_ID>
  <Terms>Waist left side point</Terms>
  <Body_Code>WS</Body_Code>
  <Description>On the left side imaginary line) The left side point on the horizontal line at the natural waist, which is the narrowest point around the torso, below the bottom rib and above the hip bones.</Description>
</Landmarks>

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  <MMP_Term>SDwbxx</MMP_Term>
  <Landmark_ID>SDpxs1</Landmark_ID>
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  <Terms>ankle</Terms>
  <MMP_Term>AKps11</MMP_Term>
  <Landmark_ID>AKps11</Landmark_ID>
  <Description>in anatomy, the joint between the foot and the lower leg</Description>
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  <Terms>ankle girth</Terms>
  <MMP_Term>AKgx1x</MMP_Term>
  <Landmark_ID>AKps11</Landmark_ID>
  <Description>in body measurements, the circumference of the leg over the greatest prominence of the ankle</Description>
</MMP_List>

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</MMP_List>
</MMP_List>
<Terms>ankle height</Terms>
</MMP_Term>
</MMP_ID>AKps11_FLpsi1</MMP_ID>
</Landmark_ID>AKps11</Landmark_ID>
</Description>in body measurements, with the subject standing barefoot, the distance from the center of the prominent outside ankle bone to the floor.</Description>
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<Terms>arm length</Terms>
</MMP_Term>
</MMP_ID>SDpx1+90de</MMP_ID>
</Landmark_ID>SDpx1</Landmark_ID>
</Description>in body measurements, with the arm bent at 90° and the clenched fist placed on the hip, the distance from the shoulder joint along the outside of the arm over the elbow to the greatest prominence on the outside of the wrist.</Description>
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<Terms>axle hole</Terms>
</MMP_Term>
</MMP_ID>SDpx1</MMP_ID>
</Landmark_ID>SDpx1</Landmark_ID>
</Description>in garment construction, the area of a garment through which the arm passes or into which a sleeve is fitted. (Compare armscye.)</Description>
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</MMP_List>
<Terms>axle pit</Terms>
</MMP_Term>
</MMP_ID>APps1</MMP_ID>
</Landmark_ID>APps1</Landmark_ID>
</Description>in anatomy, the hollow under the junction of the arm and the shoulder.</Description>
</MMP_List>
</MMP_List>
<Terms>back-break point</Terms>
</MMP_Term>
</MMP_ID>BRpx1</MMP_ID>
</Landmark_ID>BRpx1</Landmark_ID>
</Description>in anatomy, the location on the back of the body where the arm separates from the body.</Description>
</MMP_List>
</MMP_List>
<Terms>back width</Terms>
</MMP_Term>
</MMP_ID>BRwbxx</MMP_ID>
</Landmark_ID>BRwbxx</Landmark_ID>
</Description>in body measurements, the distance from back-break point to back-break point. (Syn. Cross back width.)</Description>
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<Terms>body weight</Terms>
</MMP_Term>
</MMP_ID>WT</MMP_ID>
</Landmark_ID>WT</Landmark_ID>
</Description>in body measurements, mass in kilograms (pounds).</Description>
</MMP_List>
</MMP_List>
<Terms>bust girth</Terms>
</MMP_Term>
</MMP_ID>(Bugxx)pa</MMP_ID>
</Landmark_ID>(Bugxx)pa</Landmark_ID>
<Description>in body measurements, the circumference of the body over the fullest part of the breasts and parallel to the floor. (Syn. Bust, full-bust girth.) (Compare upper chest girth, under bust girth)</Description>

</MMP_List>

<Terms>bust point to bust point</Terms>

<MMP_Term>BUpfx1_BUpfx2</MMP_Term>

<MMP_ID>BUpfx1_BUpfx2</MMP_ID>

<Landmark_ID>BUpfx1</Landmark_ID>

<Description>in body measurements, the distance across from the apex of one breast to the apex of the other.</Description>

</MMP_List>

<Terms>calf girth</Terms>

<MMP_Term>(CLgx1)xpa</MMP_Term>

<MMP_ID>maxCLgx1x@KNgx1x+AKgx1x)xpa</MMP_ID>

<Landmark_ID>KNpfx10</Landmark_ID>

<Description>in body measurements, the maximum circumference around the leg between the knee and ankle, parallel to the floor.</Description>

</MMP_List>

<Terms>center back waist length</Terms>

<MMP_Term>NKpbx0_WSpx0</MMP_Term>

<MMP_ID>NKpbx0_WSpx0</MMP_ID>

<Landmark_ID>NKpbx0</Landmark_ID>

<Description>in body measurements, the vertical distance along the spine from the cervicale to the waist.</Description>

</MMP_List>

<Terms>center front waist length</Terms>

<MMP_Term>NKpx0_WSpx0</MMP_Term>

<MMP_ID>NKpx0_WSpx0</MMP_ID>

<Landmark_ID>NKpx0</Landmark_ID>

<Description>in body measurements, the vertical distance from the neck baseline at the center front to the waist level.</Description>

</MMP_List>

<Terms>cervicale</Terms>

<MMP_Term>NKpbx0</MMP_Term>

<MMP_ID>NKpbx0</MMP_ID>

<Landmark_ID>NKpbx0</Landmark_ID>

<Description>in anatomy, the prominent point of the seventh or lowest neck vertebra at the back of the body. The cervicale is identified by being more prominent when the head is bent forward; however, cervicale height measurements are made only when the head is erect.</Description>

</MMP_List>

<Terms>cervicale to bust point</Terms>

<MMP_Term>NKpbx0_SNpx1_BUpfx1</MMP_Term>

<MMP_ID>NKpbx0_SNpx1_BUpfx1</MMP_ID>

<Landmark_ID>NKpbx0</Landmark_ID>

<Description>in body measurements, the distance from the cervicale around the base of the neck and down to the bust point.</Description>

</MMP_List>

<Terms>cervicale to wrist</Terms>

<MMP_Term>NKpbx0_AMlx1x+90de</MMP_Term>

<MMP_ID>NKpbx0_AMlx1x+90de</MMP_ID>

<Landmark_ID>NKpbx0</Landmark_ID>

<Description>in body measurements, with the arm bent, the distance from the cervicale to the shoulder joint, along the outside of the arm, over the elbow to the greater prominence on the outside of the wrist.</Description>

</MMP_List>
<MMP_List>
  <Terms>cross-chest width</Terms>
  <MMP_Term>CHwfxxx</MMP_Term>
  <MMP_ID>BRpfx1_BRpfx2</MMP_ID>
  <Landmark_ID>BRpfx1</Landmark_ID>
  <Description>in body measurements, the distance from front-break point to front-break point.</Description>
  </MMP_List>

<MMP_List>
  <Terms>crown</Terms>
  <MMP_Term>HDpxx0</MMP_Term>
  <MMP_ID>HDpxx0</MMP_ID>
  <Landmark_ID>HDpxx0</Landmark_ID>
  <Description>in anatomy, the top of the head.</Description>
  </MMP_List>

<MMP_List>
  <Terms>drop</Terms>
  <MMP_Term>CHgxxx-WSgxx</MMP_Term>
  <MMP_ID>CHgxxx-WSgxx0</MMP_ID>
  <Landmark_ID>WSgxx0</Landmark_ID>
  <Description>in body measurements, the difference between the chest girth and the waist girth.</Description>
  </MMP_List>

<MMP_List>
  <Terms>elbow</Terms>
  <MMP_Term>ELpb10</MMP_Term>
  <MMP_ID>ELpb10</MMP_ID>
  <Landmark_ID>ELpb10</Landmark_ID>
  <Description>in anatomy, the joint which articulates between the upper arm and the lower arm.</Description>
  </MMP_List>

<MMP_List>
  <Terms>elbow girth</Terms>
  <MMP_Term>ELgxx×90de</MMP_Term>
  <MMP_ID>ELpb10_ELpb10+90de</MMP_ID>
  <Landmark_ID>ELpb10</Landmark_ID>
  <Description>in body measurements, with the arm bent at 90° and the clenched fist placed on the hip, the circumference of the elbow.</Description>
  </MMP_List>

<MMP_List>
  <Terms>front-break point</Terms>
  <MMP_Term>BRpfx1</MMP_Term>
  <MMP_ID>BRpfx1</MMP_ID>
  <Landmark_ID>BRpfx1</Landmark_ID>
  <Description>in anatomy, the location on the front of the body where the arm separates from the body.</Description>
  </MMP_List>

<MMP_List>
  <Terms>front high-hip</Terms>
  <MMP_Term>WHpfx0</MMP_Term>
  <MMP_ID>WSpfx0-3in</MMP_ID>
  <Landmark_ID>WSpfx0</Landmark_ID>
  <Description>in body measurements, the distance from one imaginary side seam to the other imaginary side seam at the high-hip level. (Syn. abdominal extension.)</Description>
  </MMP_List>

<MMP_List>
  <Terms>head girth</Terms>
  <MMP_Term>HDg</MMP_Term>
  <MMP_ID>HDg</MMP_ID>
  <Landmark_ID>HDpxx0</Landmark_ID>
  <Description>in body measurements, the maximum circumference of the head above the ears. In the industry, the term head circumference is preferred.</Description>
  </MMP_List>
<MMP_List>
  <MMP_List>
    <Terms>height</Terms>
    <MMP_Term>HDPxx_FLPxx</MMP_Term>
    <MMP_ID>HDPxx_FLPxx</MMP_ID>
    <Landmark_ID>FLpxx0</Landmark_ID>
    <Description>in body measurements, the vertical distance from the crown of a standing subject to the soles of the feet. (Syn. stature)</Description>
  </MMP_List>
  <MMP_List>
    <Terms>high-hip girth</Terms>
    <MMP_Term>HPgxxx</MMP_Term>
    <MMP_ID>maxHPgxxx</MMP_ID>
    <Landmark_ID>WSpfx0</Landmark_ID>
    <Description>in body measurements, the circumference of the body at a point approximately 7.5 cm (3 in.) below the waist and parallel to the floor. (Compare hip girth.)</Description>
  </MMP_List>
  <MMP_List>
    <Terms>hip girth</Terms>
    <MMP_Term>CRpfx0_FLpfx0</MMP_Term>
    <MMP_ID>CRpfx0</MMP_ID>
    <Landmark_ID>CRpfx0</Landmark_ID>
    <Description>in body measurements, the maximum circumference of the buttocks.</Description>
  </MMP_List>
  <MMP_List>
    <Terms>inside-leg length</Terms>
    <MMP_Term>KNpf10</MMP_Term>
    <MMP_ID>KNpf10</MMP_ID>
    <Landmark_ID>KNpf10</Landmark_ID>
    <Description>in anatomy, the joint between the lower and upper leg.</Description>
  </MMP_List>
  <MMP_List>
    <Terms>knee girth</Terms>
    <MMP_Term>KNpf10</MMP_Term>
    <MMP_ID>KNpf10</MMP_ID>
    <Landmark_ID>KNpf10</Landmark_ID>
    <Description>in body measurements, with the leg straight, the circumference of the knee over the knee cap and parallel to the floor.</Description>
  </MMP_List>
  <MMP_List>
    <Terms>mid-neck girth</Terms>
    <MMP_Term>SNpsx1_NKpfx0</MMP_Term>
    <MMP_ID>SNpsx1_NKpfx0</MMP_ID>
    <Landmark_ID>NKpfx0</Landmark_ID>
    <Description>in body measurements, the circumference of the neck approximately 25 mm (1 in.) above the neck base. (Compare neck base girth.)</Description>
  </MMP_List>
  <MMP_List>
    <Terms>mid-thigh girth</Terms>
    <MMP_Term>midTHgs1x</MMP_Term>
    <MMP_ID>midTHgs1x</MMP_ID>
    <Landmark_ID>KNpf10</Landmark_ID>
  </MMP_List>
</MMP_List>
<Description>in body measurements, the circumference of the upper leg between the hip and the knee.</Description>
</MMP_List>

<MMP_List>
<Terms>neck base girth</Terms>
<MMP_Term>NKpx0</MMP_Term>
<MMP_ID>SNpx1_NKpx0_SNpx2</MMP_ID>
<Landmark_ID>NKpx0</Landmark_ID>
<Description>in body measurements, the circumference of the neck over the cervicale at the back and at the top of the collarbone at the front.</Description>
</MMP_List>

<MMP_List>
<Terms>outside-leg length</Terms>
<MMP_Term>WSpx1_FTps11</MMP_Term>
<MMP_ID>WSpx1_FTps11</MMP_ID>
<Description>in body measurements, the distance from the side waist to the soles of the feet, following the curve of the body.</Description>
</MMP_List>

<MMP_List>
<Terms>scye depth</Terms>
<MMP_Term>SYlpx0</MMP_Term>
<MMP_ID>NKpx0</MMP_ID>
<Landmark_ID>NKpx0</Landmark_ID>
<Description>in body measurements, the distance from in body measurements, the distance from the cervicale to a point level with the armpit.</Description>
</MMP_List>

<MMP_List>
<Terms>shoulder circumference</Terms>
<MMP_Term>SDgx0</MMP_Term>
<MMP_ID>SDpx1_SDpx2_SDpx1</MMP_ID>
<Landmark_ID>SDpx1</Landmark_ID>
<Description>in body measurements, with arms down at sides, the maximum distance around the shoulders at the top of the arms.</Description>
</MMP_List>

<MMP_List>
<Terms>shoulder joint</Terms>
<MMP_Term>SDpx1</MMP_Term>
<MMP_ID>SDpx1</MMP_ID>
<Landmark_ID>SDpx1</Landmark_ID>
<Description>in anatomy, the juncture of the collarbone and the shoulder blade. (See also acromion.) The outer end of the collarbone or clavicle pivots against the acromion which in turn pivots against the humerus or upper arm bone in the arm. These bones form the shoulder girdle.</Description>
</MMP_List>

<MMP_List>
<Terms>shoulder length</Terms>
<MMP_Term>SDlx1</MMP_Term>
<MMP_ID>SNpx1_SDpx1</MMP_ID>
<Landmark_ID>SDpx1</Landmark_ID>
<Description>in body measurements, the distance from the side neck base to the armscyne line at the shoulder joint.</Description>
</MMP_List>

<MMP_List>
<Terms>shoulder slope</Terms>
<MMP_Term>SNpx1?de</MMP_Term>
<MMP_ID>SNpx1?de</MMP_ID>
<Landmark_ID>SNpx1</Landmark_ID>
<Description>in body measurements, the angle formed when the slant of the shoulder line deviates from the horizontal line that originates at the side neck base.</Description>
</MMP_List>
< Terms>sitting spread</Terms>
< MMP_Term>SSgbx</MMP_Term>
< MMP_ID>SSgbx</MMP_ID>
< Landmark_ID>HPtsx1</Landmark_ID>
< Description>in body measurements, with the subject seated on a rigid flat surface and the thighs together, the distance around the hips (diagonally) from the point where the back of the buttocks contacts the sitting surface and over the widest part of the hips. </Description>
</MMP_List>
< Terms>thigh girth</Terms>
< MMP_Term>THgx1x</MMP_Term>
< MMP_ID>maxTHgs1x@/CRpx0-KNgx1x</MMP_ID>
< Landmark_ID>HPtsx1</Landmark_ID>
< Description>in body measurements, the maximum circumference of the upper leg close to the crotch. (Compare mid-thigh girth.) </Description>
</MMP_List>
< Terms>total crotch length</Terms>
< MMP_Term>WSpx0</MMP_Term>
< MMP_ID>WSpx0</MMP_ID>
< Landmark_ID>WSpx0</Landmark_ID>
< Description>in body measurements, the distance from the waist level at center front through the crotch to the waist level at center back. </Description>
</MMP_List>
< Terms>total vertical trunk length</Terms>
< MMP_Term>TGxxx</MMP_Term>
< MMP_ID>1/2(SDpxx1_SNpxx1 X CRpxx0 BUpxx1_1/2(SDpxx1_SNpxx1)</MMP_ID>
< Landmark_ID>SDpxx1</Landmark_ID>
< Description>in body measurements, the distance from the right shoulder line midway between the neck base and the shoulder joint, down the back through the crotch and over the projection of the right breast to the starting point. crotch and over the projection of the right breast to the starting point. </Description>
</MMP_List>
< Terms>true rise</Terms>
< MMP_Term>WSpxx1 FLTpxx1</MMP_Term>
< MMP_ID>WSpxx1 FLTpxx1</MMP_ID>
< Landmark_ID>WSpxx1</Landmark_ID>
< Description>in body measurements, the vertical distance (plumb line) from the waist level at the side to the crotch. (Syn. crotch depth.) </Description>
</MMP_List>
< Terms>underarm length</Terms>
< MMP_Term>APpxx1 WRPxx12</MMP_Term>
< MMP_ID>APpxx1 WRPxx12</MMP_ID>
< Landmark_ID>APpxx1</Landmark_ID>
< Description>in body measurements, with arm hanging down, the distance from the armpit to the inner wrist bone. </Description>
</MMP_List>
< Terms>underbust girth</Terms>
< MMP_Term>Bugxxp-xin</MMP_Term>
< MMP_ID>Bugxxp-xin</MMP_ID>
< Landmark_ID>BUpxx1</Landmark_ID>
< Description>in body measurements, the circumference of the body under the breasts and parallel to the floor. </Description>
</MMP_List>
< Terms>upper-arm girth</Terms>
< MMP_Term>BCgsx1</MMP_Term>
in body measurements, the maximum circumference of the arm usually midway between the elbow and the shoulder joint.</Description>
</MMP_List>

</MMP>

</MMP_ID>
<Landmark_ID>ELpb10</Landmark_ID>

</Terms> upper-arm length</Terms>
<MMP_Term>SDpsi1_ELpb10+90de</MMP_Term>
<MMP_ID>SDpsi1_ELpb10+90de</MMP_ID>

</Landmark_ID>SDpsi1</Landmark_ID>

</Terms> upperchest girth</Terms>
<MMP_Term>CHgxx</MMP_Term>
<MMP_ID>APpsi1_APpsi2_APpsi3</MMP_ID>

</Landmark_ID>APpsi1</Landmark_ID>

</Terms> waist</Terms>
<MMP_Term>WSgx1</MMP_Term>
<MMP_ID>WSpsi1_WSpsi0_WSpsi2_WSpsi0</MMP_ID>

</Landmark_ID>WSpsi0</Landmark_ID>

</Terms> waist girth</Terms>
<MMP_Term>WSgx0</MMP_Term>
<MMP_ID>WSpsi1_WSpsi0_WSpsi2_WSpsi0</MMP_ID>

</Landmark_ID>WSpsi0</Landmark_ID>

</Terms> wrist</Terms>
<MMP_Term>WRpx11</MMP_Term>
<MMP_ID>WRpx11</MMP_ID>

</Landmark_ID>WRpx11</Landmark_ID>

</Terms> wrist girth</Terms>
<MMP_Term>WRpx1tx</MMP_Term>
<MMP_ID>WRpx11_WRpx12_WRpx11</MMP_ID>

</Landmark_ID>WRpx11</Landmark_ID>

</Terms> forearm bones</Terms>

</MMP_ID> BCgs1x</MMP_ID>

<Landmark_ID>ELpb10</Landmark_ID>

<Description> in body measurements, with the arm bent, the distance from the shoulder joint along the outside of the arm to the prominence of the elbow.</Description>
</MMP_List>

</MMP_ID> APpsi1</MMP_ID>

</Landmark_ID>APpsi1</Landmark_ID>

</Terms> in anatomy, the part of the body at the location between the lowest rib and hip identified by bending the body to the side.</Description>
</MMP_List>

</MMP_ID> WSpsi0</MMP_ID>

</Landmark_ID>WSpsi0</Landmark_ID>

</Terms> in body measurements, the circumference of the waist immediately below the lowest rib.</Description>
</MMP_List>

</MMP_ID> WSpsi0</MMP_ID>

</Landmark_ID>WSpsi0</Landmark_ID>

</Terms> in body measurements, the maximum in anatomy, the joint which articulates between the end of the lower arm and the hand.</Description>
</MMP_List>

</MMP_ID> WSpsi0</MMP_ID>

</Landmark_ID>WSpsi0</Landmark_ID>

</Terms> in body measurements, the circumference over the prominence of the inner and the outer forearm bones.</Description>
</MMP_List>

</MMP>
Appendix D. Body Scan Data Schema (04 Body scan data.xsd)

```xml
<?xml version="1.0" encoding="UTF-8"?>
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema">
  <xs:element name="Measurements">
    <xs:annotation>
      <xs:documentation>Body measurements in each scanned body.</xs:documentation>
    </xs:annotation>
    <xs:complexType>
      <xs:sequence>
        <xs:element ref="Scan_ID"/>
        <xs:element name="MMP_ID">
          <xs:annotation>
            <xs:documentation>MMP_ID is refer to MMP terms of body measurements. Find your terms in MMP_List. The List is available in the MMPxml. If you need MMPxml, email to shwang@unity.ncsu.edu.</xs:documentation>
          </xs:annotation>
          <xs:simpleType>
            <xs:restriction base="xs:string">
              <xs:maxLength value="255"/>
            </xs:restriction>
          </xs:simpleType>
        </xs:element>
        <xs:element name="Terms" type="xs:string">
          <xs:annotation>
            <xs:documentation>Body measurement terminology on your terms. But I each terms has to have MMP_ID.</xs:documentation>
          </xs:annotation>
        </xs:element>
        <xs:element name="Measure" type="xs:double">
          <xs:annotation>
            <xs:documentation>Measurement data.</xs:documentation>
          </xs:annotation>
        </xs:element>
        <xs:element name="Unit">
          <xs:annotation>
            <xs:documentation>Unit of body measurements</xs:documentation>
          </xs:annotation>
        </xs:element>
        <xs:element name="Scan__Landmarks">
          <xs:annotation>
            <xs:documentation>Landmarks that identify each scanned body measurement.</xs:documentation>
          </xs:annotation>
        </xs:element>
        <xs:element name="Scan_ID">
          <xs:annotation>
            <xs:documentation>Each customer has each scan ID when they were scanned.</xs:documentation>
          </xs:annotation>
        </xs:element>
      </xs:sequence>
    </xs:complexType>
  </xs:element>
</xs:schema>
```
<xs:simpleType>
  <xs:restriction base="xs:string">
    <xs:minLength value="50"/>
  </xs:restriction>
</xs:simpleType>

<xs:element name="Landmark_ID">
  <xs:documentation>Landmark ID has to be found in the MMPxml file. If you need MMPxml file, email to shwang@unity.ncsu.edu</xs:documentation>
  <xs:annotation>
    <xs:documentation>Landmark ID has to be found in the MMPxml file. If you need MMPxml file, email to shwang@unity.ncsu.edu</xs:documentation>
    <xs:restriction base="xs:string">
      <xs:minLength value="50"/>
    </xs:restriction>
  </xs:element>
</xs:simpleType>

<xs:element name="Landmark_Term" type="xs:string">
  <xs:documentation>Landmark terminology in your terms. But each terms has to have "Landmark_ID".</xs:documentation>
  <xs:annotation>
    <xs:documentation>Landmark terminology in your terms. But each terms has to have "Landmark_ID".</xs:documentation>
    <xs:restriction base="xs:string">
      <xs:minLength value="50"/>
    </xs:restriction>
  </xs:element>
</xs:simpleType>

<xs:element name="Location_X">
  <xs:documentation>Each landmark's location in X coordination on the screen.</xs:documentation>
  <xs:annotation>
    <xs:documentation>Each landmark's location in X coordination on the screen.</xs:documentation>
    <xs:restriction base="xs:string">
      <xs:minLength value="50"/>
    </xs:restriction>
  </xs:element>
</xs:simpleType>

<xs:element name="Location_Y">
  <xs:documentation>Each landmark's location in Y coordination on the screen.</xs:documentation>
  <xs:annotation>
    <xs:documentation>Each landmark's location in Y coordination on the screen.</xs:documentation>
    <xs:restriction base="xs:string">
      <xs:minLength value="50"/>
    </xs:restriction>
  </xs:element>
</xs:simpleType>

<xs:element name="Location_Z">
  <xs:documentation>Each landmark's location in Z coordination on the screen.</xs:documentation>
  <xs:annotation>
    <xs:documentation>Each landmark's location in Z coordination on the screen.</xs:documentation>
    <xs:restriction base="xs:string">
      <xs:minLength value="50"/>
    </xs:restriction>
  </xs:element>
</xs:simpleType>

<xs:element name="Unit">
  <xs:documentation>Unit of Landmark location</xs:documentation>
  <xs:annotation>
    <xs:documentation>Unit of Landmark location</xs:documentation>
    <xs:restriction base="xs:string">
      <xs:minLength value="50"/>
    </xs:restriction>
  </xs:element>
</xs:simpleType>
</xs:sequence>
</xs:complexType>
</xs:element>
<xs:element name="Scan_Company">
  <xs:annotation>
    <xs:documentation>Body scan company name and contact information. It includes scanner name that is their products. </xs:documentation>
  </xs:annotation>
  <xs:complexType>
    <xs:sequence>
      <xs:element name="Company_Name">
        <xs:annotation>
          <xs:documentation>Body scan company name</xs:documentation>
        </xs:annotation>
        <xs:complexType>
          <xs:simpleType>
            <xs:restriction base="xs:string">
              <xs:maxLength value="50"/>
            </xs:restriction>
          </xs:simpleType>
        </xs:complexType>
      </xs:element>
      <xs:element name="Scanner" maxOccurs="unbounded">
        <xs:annotation>
          <xs:documentation>Name of scanner</xs:documentation>
        </xs:annotation>
        <xs:complexType>
          <xs:simpleType>
            <xs:restriction base="xs:string">
              <xs:maxLength value="50"/>
            </xs:restriction>
          </xs:simpleType>
        </xs:complexType>
      </xs:element>
      <xs:element name="Website" type="xs:anyURI">
        <xs:annotation>
          <xs:documentation>Company website address</xs:documentation>
        </xs:annotation>
      </xs:element>
    </xs:sequence>
  </xs:complexType>
</xs:element>
</xs:complexType>
</xs:element>
<xs:element name="Body_Scan_Data">
  <xs:annotation>
    <xs:documentation>Root of body scan data</xs:documentation>
  </xs:annotation>
  <xs:complexType>
    <xs:sequence>
      <xs:element name="Document_Date" type="xs:date">
        <xs:annotation>
          <xs:documentation>Date of documentation e.g. 2001-01-01</xs:documentation>
        </xs:annotation>
      </xs:element>
      <xs:element name="Document_By" type="xs:string">
        <xs:annotation>
          <xs:documentation>Name of person documenting</xs:documentation>
        </xs:annotation>
      </xs:element>
      <xs:element name="Contact_Email" type="xs:anySimpleType">
        <xs:annotation>
          <xs:documentation>Email address of the person documenting</xs:documentation>
        </xs:annotation>
      </xs:element>
      <xs:element ref="Scan_Company" maxOccurs="unbounded"/>
      <xs:element ref="Scan_List" maxOccurs="unbounded"/>
      <xs:element ref="Measurements" maxOccurs="unbounded"/>
<xs:element ref="Scan__Landmarks" minOccurs="0" maxOccurs="unbounded"/>
</xs:sequence>
</xs:complexType>
</xs:element>
<xs:element name="Scan_List">
<xs:annotation>
<xs:documentation>First, list scan data file that is going to import/export in this documentation. It must include each Scan_ID.</xs:documentation>
<xs:documentation>Scan data list that is going to import or export measurement data. It includes each Scan_ID, file, scanner, and the scanned resolution.</xs:documentation>
</xs:annotation>
<xs:complexType>
<xs:sequence>
<xs:element name="Scan_ID">
<xs:annotation>
<xs:documentation>Each customer has each scan ID when they were scanned.</xs:documentation>
</xs:annotation>
<xs:simpleType>
<xs:restriction base="xs:string">
<xs:maxLength value="50"/>
</xs:restriction>
</xs:simpleType>
</xs:element>
<xs:element name="Measure_File">
<xs:annotation>
<xs:documentation>Measurement data file of each specified scan ID. e.g. female001.ord</xs:documentation>
</xs:annotation>
<xs:simpleType>
<xs:restriction base="xs:string">
<xs:maxLength value="50"/>
</xs:restriction>
</xs:simpleType>
</xs:element>
<xs:element name="Scan_Date" type="xs:date">
<xs:annotation>
<xs:documentation>Date of scan each body. e.g. 2001-01-15</xs:documentation>
</xs:annotation>
</xs:element>
<xs:element name="Scan_Time" type="xs:time">
<xs:annotation>
<xs:documentation>Time of scan each body. e.g. 17:45:09</xs:documentation>
</xs:annotation>
</xs:element>
<xs:element name="Scan_By" type="xs:string">
<xs:annotation>
<xs:documentation>Name of a scan operator.</xs:documentation>
</xs:annotation>
</xs:element>
<xs:element name="Scanner">
<xs:annotation>
<xs:documentation>Name of scanner that used.</xs:documentation>
</xs:annotation>
<xs:simpleType>
<xs:restriction base="xs:string">
<xs:maxLength value="50"/>
</xs:restriction>
</xs:simpleType>
</xs:element>
<xs:element name="Resolution" minOccurs="0">
<xs:annotation>
</xs:annotation>
</xs:element>
<xs:documentation>Resolution of body scan figures on the screen. </xs:documentation>
</xs:annotation>
<xs:complexType>
  <xs:restriction base="xs:string">
    <xs:maxLength value="50"/>
  </xs:restriction>
</xs:complexType>
</xs:element>
</xs:sequence>
</xs:complexType>
</xs:element>
<xs:element name="Scan_ID">
  <xs:annotation>
    <xs:documentation>Each customer has each scan ID when they were scanned. </xs:documentation>
  </xs:annotation>
  <xs:complexType>
    <xs:restriction base="xs:string">
      <xs:maxLength value="50"/>
    </xs:restriction>
  </xs:complexType>
</xs:element>
</xs:schema>
Appendix E. Body Scan Data XML (06 Body scan data.xml)

```xml
<?xml version="1.0" encoding="UTF-8"?>
<Body_Scan_Data xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="C:\Dissertation (SU XML)\MMP/XML\MMPDB_XML\02 MMP.xsd">
    <Document_Date>2003-07-24</Document_Date>
    <Document_Type>Su-Jeong Hwang Shin</Document_Type>
    <Contact_Email>shwang@unity.ncsu.edu</Contact_Email>
    <Company_Name>TCL</Company_Name>
    <Scanner>2T4</Scanner>
    <Website>http://tc2.com</Website>
</Body_Scan_Data>
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    <Terms>Bust girth</Terms>
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    <Unit>inch</Unit>
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    <Terms>Ture rise</Terms>
    <Measure>10.0394</Measure>
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252
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  <Unit>inch</Unit>
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  <Measure>9.7278</Measure>
  <Unit>inch</Unit>
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  <MMP_ID>AKps22_FLps22</MMP_ID>
  <Terms>Ankle right height</Terms>
  <Measure>2.7559</Measure>
  <Unit>inch</Unit>
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  <Scan_ID>Female_001</Scan_ID>
  <MMP_ID>APpsx1_APpsx2_APpsx1</MMP_ID>
  <Terms>Upper chest girth</Terms>
  <Measure>39.8393</Measure>
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  <Scan_ID>Female_001</Scan_ID>
  <MMP_ID>APpsx1_WRpx12</MMP_ID>
  <Terms>Underarm left length</Terms>
<Measure>18.3082</Measure>
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<Measure>18.762</Measure>
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<Scan_ID>Female_001</Scan_ID>
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<Terma>Byeep left girth</Terma>
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<Terma>Byeep right girth</Terma>
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<Scan_ID>Female_001</Scan_ID>
<MMP_ID>BAppx2</MMP_ID>
<Terma>Back width</Terma>
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</Measurements>
<Measurements>
<Scan_ID>Female_001</Scan_ID>
<MMP_ID>BAppx2</MMP_ID>
<Terma>Cross chest width</Terma>
<Measure>19.8545</Measure>
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<Scan_ID>Female_001</Scan_ID>
<MMP_ID>BAppx2</MMP_ID>
<Terma>Bust point to bust point</Terma>
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<Scan_ID>Female_001</Scan_ID>
<MMP_ID>BAppx2</MMP_ID>
<Terma>Inside leg left length</Terma>
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<Scan_ID>Female_001</Scan_ID>
<MMP_ID>BAppx2</MMP_ID>
<Terma>Inside leg right length</Terma>
<Measure>31.2717</Measure>
<Unit>inch</Unit>
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<Scan_ID>Female_001</Scan_ID>
<MMP_ID>ELpb10 ELpb10+90de</MMP_ID>
<Terms>Elbow left girth</Terms>
<Measure>9.7566</Measure>
<Unit>inch</Unit>
</Measurements>
<Measurements>
<Scan_ID>Female_001</Scan_ID>
<MMP_ID>ELpb20_ELpb20+90de</MMP_ID>
<Terms>Elbow right girth</Terms>
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<Scan_ID>Female_001</Scan_ID>
<MMP_ID>maxCLgx1x@((KNgx1x~AKgx1x))pa</MMP_ID>
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<Terms>Calf right girth</Terms>
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<Scan_ID>Female_001</Scan_ID>
<MMP_ID>maxHPgxxx@((WSgxxx~CRpxx0))</MMP_ID>
<Terms>Hip girth</Terms>
<Measure>44.9835</Measure>
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</Measurements>
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<Scan_ID>Female_001</Scan_ID>
<MMP_ID>maxTHgx1x@((CRpxx0-1in~KNgx1x))</MMP_ID>
<Terms>Thigh left girth</Terms>
<Measure>23.2594</Measure>
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<Scan_ID>Female_001</Scan_ID>
<MMP_ID>maxTHgx2x@((CRpxx0-1in~KNgx2x))</MMP_ID>
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<Measure>23.4662</Measure>
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<Scan_ID>Female_001</Scan_ID>
<MMP_ID>NKpbx0_1/2(APpxx1_APpxx2)</MMP_ID>
<Terms>Syce depth</Terms>
<Measure>6.5342</Measure>
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</Measurements>
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<Scan_ID>Female_001</Scan_ID>
<MMP_ID>NKpbx0_SDpxx1_ELpb10+90de_WRpx11</MMP_ID>
<Terms>Cervical to wrist left length</Terms>
<Measure>30.1259</Measure>
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<Measurements>
<Scan_ID>Female_001</Scan_ID>
</Measurements>
<MMP_ID>NKpbx0_WSpx0</MMP_ID>
<Terms>Back waist length</Terms>
<Measure>16.8707</Measure>
<Unit>inch</Unit>
</Measurements>

<Measurements>
<Scan_ID>Female_001</Scan_ID>
<MMP_ID>NKpbx0_WSpx0</MMP_ID>
<Terms>Front waist length</Terms>
<Measure>16.8848</Measure>
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<Measurements>
<Scan_ID>Female_001</Scan_ID>
<MMP_ID>SDpx1_BRpx1_APpx1_BRpbx1_SDpx1</MMP_ID>
<Terms>Armhole left girth</Terms>
<Measure>15.8624</Measure>
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</Measurements>

<Measurements>
<Scan_ID>Female_001</Scan_ID>
<MMP_ID>SDpx1_ELpb10+90de_WRpx11</MMP_ID>
<Terms>Armhole right girth</Terms>
<Measure>21.6756</Measure>
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<Measurements>
<Scan_ID>Female_001</Scan_ID>
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<Terms>Shoulder width</Terms>
<Measure>16.2945</Measure>
<Unit>inch</Unit>
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<Measurements>
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<MMP_ID>SDpx2_ELpb20+90de_WRpx22</MMP_ID>
<Terms>Arm right length</Terms>
<Measure>22.2056</Measure>
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<Unit>inch</Unit>
</Measurements>

<Measurements>
<Scan_ID>Female_001</Scan_ID>
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<Terms>Neck base girth</Terms>
<Measure>13.3636</Measure>
<Unit>inch</Unit>
</Measurements>

<Measurements>
<Scan_ID>Female_001</Scan_ID>
<MMP_ID>SNpx1_SDpx2</MMP_ID>
<Terms>Shoulder left length</Terms>
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<Unit>inch</Unit>
</Measurements>

<Measurements>

<Measurements>
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  <MMP_ID>SNpsx2?de</MMP_ID>
  <Terms>Shoulder right slope</Terms>
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  <Unit>inch</Unit>
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<Measurements>
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  <Terms>Shoulder right length</Terms>
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  <Unit>inch</Unit>
</Measurements>

<Measurements>
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  <Measure>5.9468</Measure>
  <Unit>inch</Unit>
</Measurements>

<Measurements>
  <Scan_ID>Female_001</Scan_ID>
  <MMP_ID>WRpx22_WRpx21_WRpx22</MMP_ID>
  <Terms>Wrist right girth</Terms>
  <Measure>6.0921</Measure>
  <Unit>inch</Unit>
</Measurements>

<Measurements>
  <Scan_ID>Female_001</Scan_ID>
  <MMP_ID>WSpsx1_WSpsx0_WSpsx2_WSpsx1</MMP_ID>
  <Terms>Waist girth</Terms>
  <Measure>30.5145</Measure>
  <Unit>inch</Unit>
</Measurements>

<Measurements>
  <Scan_ID>Female_001</Scan_ID>
  <MMP_ID>WSpsx1_WSpsx0_WSpsx2_WSpsx1</MMP_ID>
  <Terms>Waist girth</Terms>
  <Measure>30.5804</Measure>
  <Unit>inch</Unit>
</Measurements>

<Measurements>
  <Scan_ID>Female_001</Scan_ID>
  <MMP_ID>WSpsx1_WSpsx0_WSpsx2_WSpsx1</MMP_ID>
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  <Measure>30.5804</Measure>
  <Unit>inch</Unit>
</Measurements>

<Measurements>
  <Scan_ID>Female_001</Scan_ID>
  <MMP_ID>WSpsx1_WSpsx0_WSpsx2_WSpsx1</MMP_ID>
  <Terms>Waist girth</Terms>
  <Measure>30.5804</Measure>
  <Unit>inch</Unit>
</Measurements>

<Measurements>
  <Scan_ID>Female_001</Scan_ID>
  <MMP_ID>WSpsx1_WSpsx0_WSpsx2_WSpsx1</MMP_ID>
  <Terms>Waist girth</Terms>
  <Measure>30.5804</Measure>
  <Unit>inch</Unit>
</Measurements>

<Measurements>
  <Scan_ID>Female_001</Scan_ID>
  <MMP_ID>WSpsx1_WSpsx0_WSpsx2_WSpsx1</MMP_ID>
  <Terms>Waist girth</Terms>
  <Measure>30.5804</Measure>
  <Unit>inch</Unit>
</Measurements>

<Measurements>
  <Scan_ID>Female_001</Scan_ID>
  <MMP_ID>WSpsx1_WSpsx0_WSpsx2_WSpsx1</MMP_ID>
  <Terms>Waist girth</Terms>
  <Measure>30.5804</Measure>
  <Unit>inch</Unit>
</Measurements>

<Measurements>
  <Scan_ID>Female_001</Scan_ID>
  <MMP_ID>WSpsx1_WSpsx0_WSpsx2_WSpsx1</MMP_ID>
  <Terms>Waist girth</Terms>
  <Measure>30.5804</Measure>
  <Unit>inch</Unit>
</Measurements>

<Measurements>
  <Scan_ID>Female_001</Scan_ID>
  <MMP_ID>WSpsx1_WSpsx0_WSpsx2_WSpsx1</MMP_ID>
  <Terms>Waist girth</Terms>
  <Measure>30.5804</Measure>
  <Unit>inch</Unit>
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  <Terms>Waist girth</Terms>
  <Measure>30.5804</Measure>
  <Unit>inch</Unit>
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  <Scan_ID>Female_001</Scan_ID>
  <MMP_ID>WSpsx1_WSpsx0_WSpsx2_WSpsx1</MMP_ID>
  <Terms>Waist girth</Terms>
  <Measure>30.5804</Measure>
  <Unit>inch</Unit>
</Measurements>

<Measurements>
  <Scan_ID>Female_001</Scan_ID>
  <MMP_ID>WSpsx1_WSpsx0_WSpsx2_WSpsx1</MMP_ID>
  <Terms>Waist girth</Terms>
  <Measure>30.5804</Measure>
  <Unit>inch</Unit>
</Measurements>
<Measurements>
	<Scan_ID>Female_001</Scan_ID>
	<MMP_ID>WSpfx0_CRpfx0_WSpx0</MMP_ID>
	Terms>Total crotch length</Terms>
	<Measure>26.8376</Measure>
	<Unit>inch</Unit>
</Measurements>

<Measurements>
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	<MMP_ID>WSpdx1_(WSpdx0)_WSpx2</MMP_ID>
	Terms>Waist back width</Terms>
	<Measure>15.7359</Measure>
	<Unit>inch</Unit>
</Measurements>

<Measurements>
	<Scan_ID>Female_001</Scan_ID>
	<MMP_ID>WSpdx1_(WSpdx0)_WSpx2</MMP_ID>
	Terms>Waist front width</Terms>
	<Measure>14.7566</Measure>
	<Unit>inch</Unit>
</Measurements>

<Measurements>
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	Terms>Waist front width</Terms>
	<Measure>14.7892</Measure>
	<Unit>inch</Unit>
</Measurements>

<Measurements>
	<Scan_ID>Female_001</Scan_ID>
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	<MMP_ID>WSpdx1_(WSpdx0-2in)cu_WSpx2</MMP_ID>
	Terms>Waist front width</Terms>
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	<Unit>inch</Unit>
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	Terms>Waist front width</Terms>
	<Measure>14.7904</Measure>
	<Unit>inch</Unit>
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		<Landmark_Term/>
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		<Location_Y/>
		<Location_Z/>
	<Unit/>
</Scan_Landmarks>
</Body_Scan_Data>
Appendix F. Pattern Data Schema (10 Pattern data.xsd)

```xml
<?xml version="1.0" encoding="UTF-8"?>
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema">
  <xs:import schemaLocation="C:\Dissertation (SU XML)\Dissertation Materials\gerber XML\ASTM_SewnProductsDataSchema.xsd"/>
  <xs:element name="Alterations">
    <xs:documentation>Alteration information (Suggestion to Gerber)</xs:documentation>
    <xs:annotation>
      <xs:complexType>
        <xs:sequence>
          <xs:element name="Alt_Table" type="xs:string" maxOccurs="unbounded">
            <xs:annotation>
              <xs:documentation>Type the name you want to assign to alteration rule table</xs:documentation>
            </xs:annotation>
          </xs:element>
          <xs:element name="Unit" maxOccurs="unbounded">
            <xs:annotation>
              <xs:documentation>Inches, percentage, cm, or m in alteration rule table</xs:documentation>
            </xs:annotation>
          </xs:element>
          <xs:element ref="Alt_Rule_Name" maxOccurs="unbounded"/>
          <xs:element name="MMP_ID" type="xs:string" maxOccurs="unbounded">
            <xs:annotation>
              <xs:documentation>MMP ID that is equal to above alteration rule name. MMP_ID is available in MMPXML</xs:documentation>
            </xs:annotation>
          </xs:element>
          <xs:element name="Alt_Type" maxOccurs="unbounded">
            <xs:annotation>
              <xs:documentation>Alteration type: XY move, CCW NO Ext, CCW Ext, CW Ext, CW NO Ext, CW</xs:documentation>
            </xs:annotation>
          </xs:element>
        </xs:sequence>
        <xs:restriction base="xs:string">
          <xs:enumeration value="inch"/>
          <xs:enumeration value="%"/>
          <xs:enumeration value="cm"/>
          <xs:enumeration value="m"/>
        </xs:restriction>
      </xs:complexType>
    </xs:annotation>
  </xs:element>
</xs:schema>
```

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<xs:annotation>
  <xs:documentation>Alteration point. move point except XY move.</xs:documentation>
</xs:annotation>
</xs:element>
<xs:element name="X_move" type="xs:string" maxOccurs="unbounded">
  <xs:annotation>
    <xs:documentation>Horizontal move percentage of alteration base amount.</xs:documentation>
  </xs:annotation>
</xs:element>
<xs:element name="Y_move" type="xs:string" maxOccurs="unbounded">
  <xs:annotation>
    <xs:documentation>Vertical move percentage of alteration base amount.</xs:documentation>
  </xs:annotation>
</xs:element>
<xs:element name="Alt_Rule_Name" type="xs:string">
  <xs:annotation>
    <xs:documentation>Type the name you want to assign to current alteration rule. e.g. waist girth, skirt length.</xs:documentation>
  </xs:annotation>
</xs:element>
<xs:element name="Size_Tables">
  <xs:annotation>
    <xs:documentation>Size table information (Suggeston to Gerber)</xs:documentation>
  </xs:annotation>
  <xs:complexType>
    <xs:sequence>
      <xs:element ref="SizeName" maxOccurs="unbounded"/>
      <xs:element ref="SizeId" type="xs:integer" maxOccurs="unbounded"/>  
      <xs:element name="Unit" maxOccurs="unbounded">
        <xs:annotation>
          <xs:documentation>cm, m, inch in size table</xs:documentation>
        </xs:annotation>
        <xs:simpleType>
          <xs:restriction base="xs:string">
            <xs:enumeration value="cm"/>
            <xs:enumeration value="m"/>
            <xs:enumeration value="inch"/>
          </xs:restriction>
        </xs:simpleType>
      </xs:element>
    </xs:sequence>
    <xs:element ref="Alt_Rule_Name" maxOccurs="unbounded">
      <xs:annotation>
        <xs:documentation>Actual size of the piece you want to alter or ordered size.</xs:documentation>
      </xs:annotation>
    </xs:element>
    <xs:element name="MMP_ID" type="xs:string" maxOccurs="unbounded">
      <xs:annotation>
        <xs:documentation>MMP_ID is primary key for identifying body parts. Any body measurement terms must include MMP_ID. Question Email to:shwang@unity.ncsu</xs:documentation>
      </xs:annotation>
    </xs:element>
    <xs:element name="Measure" type="xs:double" maxOccurs="unbounded">
      <xs:annotation>
        <xs:documentation>Measure amount in size table</xs:documentation>
      </xs:annotation>
    </xs:element>
  </xs:complexType>
</xs:element>
</xs:complexType>
</xs:element>
<xs:element name="Pattern">
  <xs:annotation>
    <xs:documentation>Root element for pattern, alteration, and size table</xs:documentation>
  </xs:annotation>
  <xs:complexType>
    <xs:sequence>
      <xs:element ref="PatternData"/>
      <xs:element ref="Alterations" maxOccurs="unbounded"/>
      <xs:element ref="Size_Tables" maxOccurs="unbounded"/>
      <xs:element ref="GradingData" maxOccurs="unbounded"/>
    </xs:sequence>
  </xs:complexType>
</xs:element>
</xs:schema>
Appendix G. Pattern Data XML (11 Sample pattern data.xml)

```xml
<?xml version="1.0" encoding="UTF-8"?>
<Pattern xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="C:\Dissertation (SU XML)\MMP_XML\MMPDB_XML\10 Pattern data.xsd">
  <PatternData>
    <StyleName>DRESS</StyleName>
    <PatternDataDetails>
      <VendorName>Gerber Technology Inc.</VendorName>
      <Application>AccuMark</Application>
      <ApplicationReleaseVer>7.6.3</ApplicationReleaseVer>
      <Units>English</Units>
    </PatternDataDetails>
    <HistoryNotes>
      <Author>Su-Jeong H Shin</Author>
      <Date>10-03-03</Date>
      <Comment>First experiment of Body measurement and pattern data exchange with XML format.</Comment>
    </HistoryNotes>
    <ChangeType>Modification</ChangeType>
    <Pieces NumberOfPieces="4">
      <Piece PieceId="101">
        <PieceName>SQSHIFTBK</PieceName>
        <PieceQuantity>
          <Lefts>1</Lefts>
          <Rights>2</Rights>
        </PieceQuantity>
        <MarkingPieceAttributes SpecifiedExternally="false">
          <Rotation/>
          <ValidRotations/>
          <Flip>X</Flip>
          <MaximumTilt/>
          <TiltIncrement/>
          <Fold>DoNotFold</Fold>
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