Men’s Jeans Fit Based on Body Shape Categorization

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MEN’S JEANS FIT BASED ON BODY SHAPE CATEGORIZATION

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Textile, Apparel and Merchandising

by

Elahe Saeidi
B.S., Shiraz Azad University, May 2007
M.S., the University of Alabama, 2015
May 2019
This dissertation is dedicated to

My beloved husband, Dr. Behrouz Khodadadi

My Parents, Mr. Esmaeil Saeidi and Mrs. Shahla Mardani
Acknowledgments

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Abstract

The purpose of this study was to categorize lower body shape in men and to investigate the interplay between body shape and fitting issues appearing in men’s jeans. More specifically, the goal of the study was to improve apparel fit based on body shape. The detailed objectives of the study were to: (1) Categorize male body shapes using statistical analysis; (2) use 3D virtual fitting technology to assess fit and develop a shape-driven pants block pattern for each body shape.

This quantitative study was conducted in three stages: (1) categorizing the body shape of 1420 male scans, aged 18-35, from the SizeUSA dataset, (2) develop a shape-driven pants block pattern for each identified body shape, and (3) validate the developed blocks by virtually trying the shape-driven block pattern on fit testers from different body shape groups.

Exploratory Factor Analysis (EFA) and cluster analysis were used for body shape categorization, which resulted in three different body shapes: (1) Flat-Straight, (2) Moderate Curvy-Straight, and (3) Curvy. Three fit models were selected from each identified body shape group and then patterns were developed using Armstrong’s (2005) jeans foundation method. Patterns were modified and fitted to the selected representative fit models of each body shape group. The developed shape-driven block patterns were simulated on the fit testers to further explore the relationship between body shape and fit issues.

This study suggests that two individuals with identical body measurements may experience very different fit problems tailored to their different body shapes. It was found that each body shape would exclusively experience unique fit issues. Furthermore, the shape driven block patterns were found to be highly correlated with their host body shape category. This research implies that if the mass customization process starts with block patterns that are
engineered for specific body shape categories significantly less fit issues would appear and the desired fit would be achieved in fewer fitting sessions.
CHAPTER 1. INTRODUCTION

The clothing industry in the United States (U.S.) accounted for over $187.13 billion in 2015 (Statista, 2018a) with menswear valued at $8.8 billion (Statista, 2018b). As fashion has shifted from formal to casual wear, denim items have become accepted as semi-formal clothing articles and continue to be a popular staple due to their comfort (Regan, 2015). In 2015, Cotton Incorporated reported that more than 6 in 10 consumers (67%) prefer to wear denim jeans over casual slacks. According to Cotton Inc. (2015) the most important factors influencing the male consumer to buy denim jeans are: fit (64%), followed by comfort (60%), durability (54%), quality (53%), price (51%), and style 31%.

1.1 Fit Issues in Ready-to-Wear Apparel

The industrial revolution permanently changed the apparel and textile industry giving way to the ready-to-wear clothing market (Brown & Rice, 2014). Ready-to-wear (RTW) clothing is factory-made clothing that is mass produced in standardized sizes for a target population (Brown & Rice, 2014). Consumers had the choice of purchasing custom-fitted garments from a tailor or dressmaker or ones that were mass-produced and sold in stores (Pandarum & Yu, 2015). The popularity of ready-to-wear quickly grew due to its immediate availability and cost effectiveness making it the primary source of clothing production in the world for over half of the 20th century (Ashdown, 2014). Mass producing ready-to-wear clothing, however, has brought both advantages and disadvantages to the consumer. Mpampa, Azariadis and Sapidis (2010) observed that while improving production volume, the fit and design of clothing have been negatively impacted by mass production methods.
Mass producing apparel presents a major obstacle for manufactures. Apparel manufacturers do not know the precise measurements of the consumer who will purchase their clothing. Therefore, producing well-fitting garments is a challenge. To address this challenge standardized sizes were created (Buckland, 2010). Standardized sizing has been defined as the method of classifying body types and sizes so as to provide size increments for the production of apparel (LaBat, 2007). Although providing guidelines for the mass production of clothing in various sizes standardized sizing is inherently flawed due to two factors: (1) availability of accurate anthropometric data reflecting the size and shape of the current population (2) the use of basic pattern blocks for various body shapes (Ashdown, 2007).

The lack of current anthropometric data that reflects the size and shape of today’s consumer is a major factor interfering with apparel manufactures’ ability to solve fitting and sizing issues (Ashdown, 2014; Connell, Ulrich, Brannon, & Presley, 2006; Devarajan & Istook, 2004; Simmon, Istook, & Devarajan, 2004a). The current apparel sizing system used in the U.S. is based on biased anthropometric data that were collected over seven decades ago and does not represent the current U.S. population (O’Brien & Sheldon, 1941). The data collected in that study were taken from persons serving in the armed forces and comprised primarily of Caucasian individuals (O’Brien & Sheldon, 1941). It is widely accepted that body shape and size is primarily dictated by genetics (Keesey, 1986). Thus, the wide variety of ethnicities and cultures present in today’s U.S. population has further complicated attempts to manufacture clothing with universal appeal and fit (Ashdown, 2014).

The second factor impeding the apparel industries ability to mass produce well-fitting garments is the use of basic pattern blocks. Basic pattern blocks are master templates, which are often adapted from the measurement of one single fit model. The fit model is assumed to reflect
the body shape and size, of the company’s target market (Ashdown, 2014; Keiser & Garner, 2008). This basic pattern block is then used to create all clothing designed by the company. As a result, consumers with body shapes different from the company’s ideal body shape experience fit issues. Additionally, all bodies that fall within the same size category may not alike. Two people can have the same circumference measurement, however, due to different body shapes their fat may be distributed differently resulting in the need for a differently shaped pattern block to achieve proper fit (Hlaing, Krzyinski, & Roedel, 2013; Petrova & Ashdown, 2008). Additionally, Ashdown and Dunne (2006) noted that some groups within the US encounter difficulty finding appropriate clothing that fit and address their style preferences.

However, recent changes have been noted in the marketplace. Historically, retailers and manufactures have dictated which products are available to consumers, but now the power is shifting to the consumer (Barrie, 2016). Hendriksz (2016) attributes this shift to consumer preferences for fit, comfort, and performance. Therefore, understanding apparel fit from consumer’s perspective is vital.

A potential way to address individual consumer preferences for fit and comfort is Made-to-measure clothing (Ashdown & Dunne, 2006; Mpampa et al., 2010). Made-to-measure clothing is produced based on an individual’s measurements. Technological developments in the apparel industry including: 3D body scanners that capture accurate body measurements; and computer-aided design (CAD) capable of generating made-to-measure digital patterns are changing the manufacturing process. By utilizing technology mass customization becomes a possible solution to improve apparel fit (Ashdown & Dunne, 2006; Mpampa et al., 2010).

It can be concluded that strategies that have been identified as having potential to overcome the fitting issues in the apparel industry require four variables be addressed (1)
variation of body shapes and sizes (2) fit preferences from the consumer’s point of viewpoint (3) fit from an industry viewpoint and (4) design features (Ashdown, 2014; Ashdown & Dunne, 2006). Therefore, successful mass customization in the apparel industry depends on the development of methods for block development that can be adapted to a diverse ensemble of body sizes and shapes (Ashdown & Dunne, 2006; Keiser & Garner, 2008; Romeo, 2013).

1.2 Importance of Basic Block

In the apparel industry, professional pattern making skills are a crucial factor in providing well-fitting garments that meet consumers fit expectations. The template from which all clothing styles are created is known by the names basic block, master pattern, or sloper. A basic block is a set of templates that have been created from two-dimensional drafting and are assumed to contain the proper measurements, angles, and ease to create a well-fitting three-dimensional garment (Glock & Kunz, 1995). Basic block patterns are used to ensure the size and body shape of the brands target customer is maintained during the design and manufacturing process. These basic blocks are used as a template to develop the stylized patterns for all clothing items offered by the brand (Lim & Cassidy, 2017). Basic block patterns ensure the brand will maintain consistent fit and appropriate wearing ease across lines. They also serve as a reference for devising a range of sizes (Lim & Cassidy, 2017).

The accuracy of a basic block is important as it is the foundation of garment creation. If the basic block is flawed, a brand cannot expect to develop clothing that will provide consumers with a satisfying fit. However, the basic blocks historically used in the apparel industry were developed for only one body shape (Pisut & Connell, 2007). To conclude, it is pivotal to develop an accurate block pattern, which follows a systematic method of pattern construction to
guarantee an appropriate fit in the final garment. It is also very important that the block pattern covers various body shapes and to be able to accommodate any clothing type or design.

1.3 Theoretical Framework

The Theory of Inventive Problem Solving (TRIZ) was used as a framework for this study. TRIZ is the Russian abbreviation for Teoria Rechennia Izobretatelskih Zadatchi (Altshuller, 1999). This theory was developed in 1946 by a Russian scientist, Genrikh Altshulle, to investigate possible common patterns and characteristics and thinking practices used by the inventors. During the course of his study he realized that the invention and development of items for patent followed certain patterns and that innovation was not a result of random incidents. He concluded, “inventiveness and creativity can be learned” (Maia, Carvalho, & Leao, 2015, p 344). These patterns shed light into the process of creative thinking that eventually would lead to an invention to solve problems (Stratton, Mann, & Otterson, 2000).

The theory of TRIZ can be used to develop and improve the functionality of a technical system by identifying technical contradictions in the system. The tools that are used to improve the functionality of system and address the contradictions are called TRIZ principles. TRIZ proposed 40 different principles, which are nothing but actions that are performed within a technical system to improve its functionality (Maia et al., 2015). The TRIZ principle of segmentation was used in this study to gain a better understanding of fit issues that are related to body shape. The principle of segmentation suggests that technical system should be broken down to different interconnected segments so that they could be investigated, and their functionality could be improved (Altshuller, 1999). In this case, each segment’s functionality
should be improved to its highpoint of performance before improving the functionality of other segments.

TRIZ provides a methodology to solve problems systematically. Altshuller claimed that inventive problems could be codified, classified, and solved methodically (1999). There are various issues that prevent the apparel industry from providing well-fitted garments. These include the lack of current anthropometric measurements, lack of accurate pattern grading methodology for mass production, and lack of information regarding fit needs for different body shapes, and also developing basic block pattern based on a single fit model (Ashdown & Dunne, 2006; Ashdown, 2014). The focus of this study was to improve the fit of male’s jeans by considering the fit needs of different body shapes.

TRIZ methodology was used to improve the fit of male’s jeans based on following premises: (a) find an ideal solution to produce an ideal design; (b) Inventively solve problems by identifying and understanding contradiction and improving of an existing system (i.e., understanding different body shapes in the current population); (c) structure the product development process systematically to eliminate contradictions such as different fit issues facing each body shape group (i.e., developing basic block pattern based on the body shape of individuals (Maia, Carvalho, & Leao, 2015; Stratton et al., 2000; Yang, Kincade, & Chen-Yu, 2015).

Following the TRIZ theory this study addressed the segment or issue of body shape in relation to fit. According TRIZ, finding a workable solution to this segment will lead to improved functionality of the apparel industry as a whole.
1.4 Study Purpose and Objectives

The purpose of this study was to investigate the need to have a different base pattern shape for each body type. The goal of the study was improving apparel fit based on the body shape. The findings of this study will provide apparel manufacturers with the information needed to manufacture jeans for men that conform their body figure with proper fit.

The detailed objectives of the study were as follow:

1. Categorize a sample of male body shapes using statistical analysis
2. Develop basic pants block pattern for each identified body shape by fitting one representative man in each group
3. Use 3D virtual fitting technology and map tension to assess the fit
4. Compare the fit of the pants created from a basic block pattern (single base pattern) with pants developed with shape-driven blocks

The goal of the study is to determine if developing blocks based on body shape can eliminate one of the issues facing the apparel industry in its transition to mass customization. The central goal of TRIZ is to creatively solve problems by understanding and identifying the contradiction. Therefore, in this study, TRIZ methodology was applied to the pattern development process to achieve the following objectives:

1. Identify different body shapes that exist in the current population: using a single block pattern for various body shapes leads to a technical contradiction and apparel fit dissatisfaction. Thus, different body shapes that exist in the population should be recognized to inventively solve the problem.
2. To develop basic block patterns for individuals with different body shapes to identify fit needs of each body type group and eventually addressing the fit issues
by developing basic block pattern for each body type to eliminate contradictions using a systematic approach.

1.5 Definition of Terms

The followings are the definitions of key terms to clarify the technical terms that will be used in this study.

**Anthropometry:** “the science of measurement and the art of application that establishes the physical geometry, mass properties, and strength capabilities of the human body” (Roebuck, 1995, p. 1).

**Apparel:** “any type of clothing worn by men, women, and children” (Calasibetta & Tortora, 2003, p. 13)

**Apparel fit:** “refer to how will the garment conforms to the three-dimensional human body. However, the principles of fit are varying from time to time, and the fashion culture, industrial norm and individual perception of fit” (Zhang, Zhang, & Xiao, 2011, p. 687).

**Avatar:** “a realistic representation of the body in shape, size, and appearance for use in 3D virtual environment” (Istook, 2011, p. 297)

**Block:** “the pattern for a basic garment without any style features added” (Beazley, 1999, p. 67).

**Body Mass Index (BMI):** “an inexpensive and easy-to-perform method of screening for weight category, for example underweight, normal or healthy weight, overweight, and obesity” (Center for Disease Control, 2015, para. 1)

**Drop value:** The drop value defines as the difference between the waist and chest girth measurement (Shin et al., 2011, p. 50).

**Ease:** “difference between the body measurements of the intended wearer and the
measurements of the finished garments” (Keiser & Garner, 2008, p. 369).

**Fit model:** “is a stationary three-dimensional form that represents the figure type of the target consumer” (Alexander, Connell, & Presley, 2005, p. 56)

**Grading:** is a “method of applying increases and decreases at points of a pattern to make the pattern larger or smaller” (Schofield & LaBat, 2005, p. 13).

**Live Model:** known as fit models, provide invaluable insight, as they can give comments about the poorly fitted areas based on the feel of the garment on their body (Song & Ashdown, 2010).

**Mass Customization:** “the application of mass-production techniques to the production of a single customer-configured garment” (Keiser & Garner, 2008, p. 376).

**Made-to-Measure:** clothing that is made to an individual’s measurements. Made-to-measure clothing can be made using different technologies and can refer to either custom-made or mass-customized clothing (“Made-to-Measure”, 2011).

**Somatotype:** “an effective technique for the description of body shape and composition. An individual’s somatotype is defined by three components named endomorphy, mesomorphy and ectomorphy” (Buffa, Floris, Putzu, Carboni, & Marini, 2007, p. 733).

**Standard Sizing:** “is a method of classifying body shapes and providing size increments for the production of apparel” (LaBat, 2007, p. 88).

**Tension Map:** is a feature of Optitex 3D to “inspect simulated cloth objects via a colored map depicting amounts of stretching, tension and distance between the cloth and the model” (Optitex Help Center, n.d).

**Virtual Fitting:** Wrapping 2D pattern around 3D virtual model to evaluate fit and accuracy of pattern (Sayem, 2017).
CHAPTER 2. REVIEW OF LITERATURE

This chapter will discuss jeans in depth through history, and its importance in Western society. It will also discuss the concept of apparel fit, the relationship of fit to body shape, how the apparel industry attempts to achieve an acceptable fit for consumers, and issues apparel manufacturers face in providing well fitted garments for the ready-to-wear market.

2.1 Jeans a Staple Garment in Western Culture

Denim is the most produced and used clothing in the U.S. today. As stated by a historian of Levis Strauss & Co. (2014), “Denim is more than just a cotton fabric; it inspires strong opinions within the hearts of historians, designers, teenagers, movie stars, reporters and writers” (Levis Strauss & Co., 2014, para.1). The inventor of this staple American garment is Levi Strauss, who upon arriving in San Francisco in 1853 opened a wholesale dry goods business. A consumer of Strauss, Jacob Davis a tailor by trade, wanted to improve the durability of laborers pants so they would not fall apart easily. He came up with the idea of putting metal rivets at the points of strain, such as button fly and corners of pockets, to make the pants strong and sturdy. When Jacob decided to patent his riveted pants, in 1872, he needed a business partner to support him to start manufacturing his new work clothing. He asked Strauss and together they received a patent in 1873 (Downey, 2014a). One of the most well-known trademarks in the history of American fashion is the image of two horses straining to tear apart a pair Levi’s first denim work pants as in Figure 2.1 (Downey, 2014b).
The first jeans, which were called “waist overall” were made out of cotton duck and blue denim with copper rivets. Due to consumer preference for denim trousers (see Figure 2.2), the company terminated manufacturing garment out of cotton duck around 1911 shifting all production to denim.

Figure 2.1. Well-known trademark of Levi’s Strauss & Co. in 1873

Figure 2.2. 1882 Gold Miners wearing Levi’s jeans. Library of Congress Getty Images
By the 1920s, the waist overall became the most used products as men’s work-wear in the Western United States (Downey, 2014a). Denim was a traditional fabric used for men’s work-wear, it was also acknowledged by American Fabrics magazines in 1969, as one of the world’s oldest fabric (Panek, 2016). Denim jeans continued to be used for work wear during the 1930’s (See Figure 2.3)

![Farmers wearing blue jeans as work wear 1930’s. Dorothea Lange, Library of Congress Getty Images](image)

During 1930s, the reputation of denim jeans `was in a transition stage and became less associated with miners, farmer, or hard work and more as a cultural symbol (Levi Strauss & Co Official Website, 2018). The first women’s denims were introduced in the form of dungarees in 1935 and 1949 by Levi Strauss and Lee respectively, which was an aftermath of Hollywood actresses such as Katherine Hepburn and Carole Lombard pictured glorious Western women wearing dungarees, as illustrated in Figure 2.4 (Comstock, 2011).
The motion picture industry boosted the image of jeans as a symbol of independence and freedom in Cowboy movies. The Economist (2016) noted:

As far back as the 1930s, when the popularity of cowboy films helped jeans make the leap from work-wear into the wardrobes of Hollywood stars, denim has been understood to stand for something larger about the American spirit: for rugged individualism, informality and a classless respect for hard work (para.1).

Hollywood capitalized on the popularity of cowboy movies from the 1930’s through 1960’s and introduced blue jeans as ranch wear for the cow girl (Figure 2.5). Due to advertising, the popularity of jeans became so widespread that persons living in the eastern US traveled to the west to purchase jeans and experience authentic cowboy dress (Downey, 2014a).
Denim production for the general public had decreased during World War II. This was due to the demand for raw material for the war effort and “Blue jeans” had become the official uniform of the US Navy and Coast Guard (Blue jeans, 2018). Simultaneously, women entered the workforce performing jobs that had previously been held by men. The symbol of the “can do” woman became Rosie the Riveter who was shown in wartime posters wearing blue jeans as she tirelessly worked building ships and tanks for the war effort (See Figure 2.6)
For decades, jeans had been the uniform of the cowboy, but after World War II they were adopted by heroes of the wartime (Levi Strauss & Co Official Website, 2018). After the war, soldiers returning home organized motorcycle clubs and adopted the jeans worn during the war as their official pants. Jeans began to take on a new reputation associated with rebellion, and rowdy behavior (Blue jeans, 2018). During the 1950s, Hollywood reinforced jeans as a symbol of rebellion with movies such as The Wild One, and Rebel Without Cause as shown in Figure 2.7 (Blue jeans, 2018).

![Figure 2.7. Rebel without a Cause (Warner Brothers Studios, 1955)](image)

Blue jeans as a symbol of wild, rebellious bad-boys led to concern on the part of the general public. In response many U.S. public high school boards ban the wearing of jeans as the school uniform, fearing that “the fabric demarcated a rebellious, rough and tumble lifestyle” (Panek, 2017). Regan (2015), noted that the rebellious reputation of jeans was so bold that some schools started banning their students from wearing any denim, in particular Levi’s pants and shirts. However, these school regulations and policies against wearing jeans were eventually relaxed during the 1960s. But, as in the past blue jeans were to be reinvented taking on a new symbol and popularity in the coming decades.
2.2 Jeans Gain Worldwide Popularity

During and after World War II, jeans had gained popularity in various parts of the world when soldiers wore them as off-duty clothing for leisure activities. In the 1950s, non-Western nations had the opportunity to wear Levi’s jeans, when Levi Strauss & Co. began retailing their commodities nationally (Downey, 2014a). As the popularity of jeans kept growing, Levi Strauss was no longer the only player in the market and competitors such as Lee and Wrangler had emerged (Ragan, 2015). In the US during the 1960’s and early 1970s, the image of jeans swung back to its rebellious state as hippies choose blue jeans as part of their uniform (see Figure 2.8). Jeans became the symbol of anti-establishment and were proudly worn by hippies and opponents of the Vietnam War (Tamony, 1973).

Figure 2.8. Hippies in flared and patched jeans, photo by Evening Standard, Library of Congress Getty Images

In Europe during the same time period, jeans also became a symbol of rebellion, freedom and independence embraced by the youth population in US and Europe (see Figure 2.9). In the
mid 1970’s a new twist on the basic denim jean was introduced (Ragan, 2015). Once considered a work uniform and moderately priced the humble jeans were elevated to high fashion runway designer status.

![Figure 2.9. French jeans advertisement from 1975](image)

The jeans industry was now facing a new radical change as it transitioned from symbol of individualism and freedom to prestigious fashionable apparel (Regan, 2015). A new target customer for the denim jeans industry was born, the high fashion designer consumer. To capture this new target customer, European entrepreneurs such as François Girbaud introduced new finishing techniques such as stonewashing (Regan, 2015) and premium jeans with prices as high as several hundred dollars became a separate sector of the jeans industry (Little & Bond 1996). These premium jeans offered superior fit and styling and were not designed for average customers (Jegethesan, Sneddon, & Soutar, 2012). Quality designers such as Calvin Klein (Figure 2.10) and Gloria Vanderbilt started investing in premium jeans and promoted the denim clothing industry to a designer status (Regan, 2015). These designer jeans were distinguishable from typical jeanswear through their style and ultra-tight fit. Many other designer jeans brands
emerged in 1980s such as US brands Guess, Jordash, Sassoon and, also designer jeans market got the attention of Europeans couture giants such as John Galliano, Giorgio Armani and Versace (Regan, 2015).

![Calvin Klein advertisement, Year 1980](image)

Figure 2.10. Calvin Klein advertisement, Year 1980

Today the premium and designer jeans market in Europe is much larger than its counterpart in the US, especially in the men’s sector and companies such Hugo Boss and Armani lead the market. The humble blue jeans have survived for over a century reinventing themselves throughout the decades. Once associated with working clothing for men in the Western US, Jeans have now become a global icon of high fashion for men, women, and children and are now the most popular clothing in the world (Downey, 2014a). However, as with any item of clothing, for jeans to maintain its position of popularity it must fit the consumer and be comfortable. This is not an easy task as we will discuss.
2.3 Concept of Apparel Fit

In the apparel industry, fit is considered as a crucial element of clothing quality and consumer satisfaction (Brown & Rice, 2014; Minott, 1978; Song & Ashdown, 2010; Workman, 1991). As already discussed, fit was an element used by designers to elevate the status of jeans to a luxury clothing item. However, it is difficult to quantify fit as it is dependent on the individual’s subjective perception. Other factors such as fashion trends, cultural influences, body shapes, sex, individual norms, and lifestyle; may result in changes in fit preferences (Pisut & Connell, 2007). Whether a garment fits well or not may be a matter of personal taste in fitting preference or it may vary with standards of current fashion (Keiser & Garner, 2008). Therefore, it is difficult to have a general definition of fit (Song & Ashdown, 2010).

Many researchers in the field of clothing and textiles have tried to understand and define clothing fit. Clothing fit refers to how well a garment conforms to an individual’s three-dimensional body (Brown & Rice, 2014). Frost (1988) explained clothing fit that contains “visual as well as physical satisfaction of the garment and its function on the body” (p. 2).

Bubonia (2014) defines fit as:

The relationship between the body and the size and styling of a garment. A properly fitting garment should provide a smooth appearance that is free of wrinkling, bugling, or sagging and should effectively function for its intended use to provide comfort for the wearer (p. 60).

Ashdown and DeLong (1995), defined fit as the interaction between garment and human body and how well the clothing interacts to a set of factors including garments grain, ease, balance, line and set. According to Ashdown, Loker, Schoenfelder, and LymanClarke (2004):

A well-fitted garment is a garment that hangs smoothly and evenly on the body, with no pulls or distortion of the fabric, straight seams, pleasing proportions, no gaping, no constriction of the body, and
adequate ease for movement. Hems are parallel to the floor unless otherwise intended, and the garment armscye and crotch do not constrict the body” (p. 3).

Similarly, other studies have defined well-fitted apparel that contains three features: wearing ease (for body movement), design ease (for desired visual effect, silhouette, and style), and no unwanted wrinkle that follows the silhouette of the body (Song & Ashdown, 2010). Gersak (2002) discussed that garment fitting is evaluated based on four principles including design, fabrication, appearance and comfort. While other researchers identified five elements to define fit, including: fabric grain; set (a smooth fit with no undesirable wrinkle); line (the manner in which the structural lines of a garment conform to the natural lines of the body); balance (the garment appears evenly on both sides from front, back and side view); ease (amount of difference between the body’s measurement and the garment measurement) (Asdown & DeLong, 1995; Keiser & Garner, 2008). Laitala, Klepp and Hauge (2011) have defined well-fitting clothing when the wearer feels comfortable and is able to move freely without any limitation from the garment. According to Stecker (1996), fit of apparel can be perceived as tightness, looseness and the shape of the garment in relation to the wearer’s body.

The perception of clothing fit is affected by fashion, cultural and ethnic differences (Manuel, Connel & Presley, 2010), individual norms, and personal taste in fitting preference (Pisut & Connell, 2007). Perception of a good fit varies by personal preference as can be seen when some individuals prefer tight garments while others prefer loose-fitting clothes (LaBat & DeLong, 1990). Regardless of personal preferences for fit, it an essential element in consumer satisfaction with their apparel.
2.4 Apparel Fit Satisfaction

In the apparel-related area, consumer fit satisfaction has received great attention as shopping behavior is strongly influenced by consumer satisfaction with the fit of clothing. Both personal and external factors play a part in a consumer’s perceived satisfaction (LaBat & DeLong, 1990). Personal factors include body cathexis and the actual physical dimensions of the consumer’s body. Body catheix or body satisfaction can affect female’s self-image and their assessment of garment fit and her preferences for fit (Secord & Jourard, 1953). External influences are the current fashion figure and social ideal body (LaBat & DeLong, 1990). Physical and psychological comfort and appearance all have been shown to influence consumer’s fit satisfaction (Frost, 1988). This illustrates the point that the preference of fit for two consumers with the same body shape and measurements may vary depending upon their personal and external influences.

Several studies have shown a relationship exists between a consumer’s perceived comfort and fit of a garment and emotional and psychological demeanor. A well-fitting garment has been shown to provide confidence, certainty, and comfort for the wearer (Alexander et al., 2005). Deckert (1999) found that apparel that fits well and is comfortable for the wearer improved one’s appearance and self-esteem. Kidd (2006) further noticed that well-fitting clothing contributed to the wearers’ perception of personal attractiveness and self-confidence.

Although finding clothing with the desired fit is important for both men and women (DesMarteau, 2000), women have long received more attention and scholarly research. Research into men’s fitting preferences and the effect of fit on their self-esteem is very limited. Therefore, results of research conducted with women may provide valuable insight into areas for future research with men.
2.5 Fit Preferences and Body Shape Research has been Conducted with Female Consumers

To date the majority of research regarding apparel fit has been conducted with women. Therefore, we will discuss some of the major findings in this area as they may apply to the male population.

It has been discovered that one factor in the satisfaction of how clothing fits is the relationship between the garments and body shape (Makhanya, Klerk, Adamski, & Mastamet-Mason, 2014; Shin & Istook; 2007; Sindicich & Black, 2011). According to Petrova and Ashdown (2008), classification of the body shape of a population is an essential factor to achieve good apparel fit. Different the body shapes resulted in different fit preferences (Alexander and Connell, 2005; Shin & Istook, 2007) such as the way the garment drape on the body, the comfort of the garment, and how the fit of the clothing will be perceived by consumers (Pisut & Connell, 2007). Additionally, one’s fit preference may change over time as a result of age, changes in lifestyle and nutrition, and increase or loss in body weight (Howarton & Lee, 2010; Pisut & Connell, 2007).

A study by Alexander et al. (2005) analyzed the garment fit of females based on four different body shapes – pear, hourglass, rectangular, and inverted triangle- in order to discover the relationship between women’s body shape and garment fit preferences. Among the finding was the conclusion that different body shapes encounter different fit problems, which resulted in garment fit preferences. A recent study by Makhanya et al. (2014) compared fit problems experienced by the same body shape in two different populations. Findings of the study revealed that even though the current sizing system for women in the US was developed based on the hourglass body shape and more than 50% of participants with triangle body shape reported
tightness at their lower bodies indicating although the shape may have been correct, the anthropometric measurements were not applicable to today’s population.

Shin and Istook (2007), examined the fit of pants/jeans among five ethnic groups. All participants were within the same size category. The researchers concluded “consumers within the same body figure type size category would not be able to find the right fit of pants/jeans within the current sizing system” (p.142). This confirmed Ashdown and Dunne’s (2006) study which found that participants with body shapes that varied from the current ideal reported a need for custom clothing as their expectations are not well met by the RTW apparel industry (Ashdown & Dunne, 2006). In studies conducted with women it can be concluded that considering body shape is a key factor to achieve good fit (Petrova & Ashdown, 2008).

2.6 Limited Research on Male Consumer Fit Preference

There are only a few published studies that have focused on male fitting preferences (Chattaraman, Simmons & Ulrich, 2013; Hogge, Baer, & Kang-Park, 1988; Oliver, Bickle, & Shim, 1993; Rahman & Navarro, 2017; Sindicich & Black, 2011; Stewart, Chattaraman & Teel, 2014;), compared to the vast amount of research focusing on dissatisfaction and fit problems of female consumers.

A few decades ago, it was assumed that men are less interested in clothing and less concerned about their appearance in comparison to women (Kwon 1997; Minshall, Winakor, & Swinney, 1982; Solomon & Schloper, 1982). However, Frith and Glesson (2004) found that men were concerned about their appearance and use their clothing as a means to hide or reveal their body. For instance, one participant said, “if I am feeling fat or unappealing, then the clothes I buy will be thicker, darker, or less revealing” another one said “I tend to wear baggy
tops to hide my stomach depending on how I am feeling about myself on the day” (Frith & Glesson, 2004, p. 44).

Fit ranked as the most important factor in men’s garment selection (Cotton Incorporated, 2015; Hogge et al., 1984), which implies that men are concerned with the comfort and fit of the garment more than the style (Cotton Incorporated, 2015; Craik, 1994). This illustrates the importance of comfort and fit in men’s preferences of their clothing.

A content analysis of comments of two fashion blogs regarding men’s shopping and consumer experience revealed that men have difficulty in finding “good, fashionable clothing that fits” them properly (Rahman & Navarro, 2017, p. s2658). This means that they have problems finding clothing that offers, both desirable style and fit based on their body shape. According to the posted comments, the authors concluded that men mostly encounter problems in finding a pair of jeans/pants or shirt with proper sleeve length. For instance, one consumer posted that “the slim pants won’t go on my leg, and the ‘loose’ fits are too baggy around my lower leg or waist” (Rahman & Navarro, 2017, p. s2683).

Sindicich and Black (2011) investigated the overall satisfaction of men with business clothing and found that there was a lack of knowledge regarding proper fit and body proportion. Results indicated that men were not satisfied with the fit of current business apparel (suits, shirts and pants). The study revealed 40% of men had fitting dissatisfaction in certain garment areas and 30% reported that they had fit issues with neck circumference, shirt sleeve length, pant length, and suit torso circumference. Sindicich and Black (2011) found a correlation between Body Mass Index (BMI) and apparel fit issues. Body Mass Index (BMI) is based on an individual’s weight in relation to height. The results showed negative correlation between suit’s length and circumference measurements. Findings indicated that short men with higher BMI had
difficulty finding a suit, which fit their upper body measurements and their height. The authors concluded “there may be a need for the short category to be split into at least two figure type groups, similar to the tall or big and tall categories that exists for tall consumers” (Sindicich & Black, 2011, p. 460). In another study, Stewart et al. (2014) assessed men’s fit issues in outdoor performance clothing in accordance to Body Mass Index (BMI) and height. The results of the study revealed BMI has influence on the fit and sizing. On the other hand, the tall men mostly addressed the length issues, such as length of the sleeve and pants. It implied the influence of height on clothing fit. Sindicich and Black (2011) also found that larger men reported finding parts of clothing to be too small, while smaller men found different parts of clothing to be too large. Additionally, they found that heavier men had greater difficulty finding shirt neck sizes to fit properly and comfortably. The heavier men also found it frustrating to find a suit that fit both the waist and chest measurement. Some reported having larger chests and smaller lower bodies; they would fit their chest measurement first. However, when buying packaged suits, it was difficult to fit both the top and bottom correctly.

Chattaraman et al. (2013) conducted a study on male fit preference in relation to age, body size, body image, and psychosocial factors on specific apparel such as jeans, khakis, dress shirts, and polo shirts. As discussed by the authors, due to lack of male body shape categorization, the influence of body shape was not included in the study, which is the aim of the current study. The author further suggested that additional studies are needed to investigate the influence of body shape on fit preference. Chattaraman et al. (2013) found that in addition to men’s body size, age influenced clothing fit preferences. It implied that with the increase in body size and age, men prefer looser fit with a higher waist level. Similarly, increases in body size and age resulted in consumer preference for looser fit for both dress shirts and polo shirts.
In another study performed on men’s fit preferences for business attire with 322 men aged 20-55 (Sindicich & Black, 2011). Men self-reported fitting issues with business clothing. There is lack of knowledge regarding desirable fit and body proportion. In most cases men with larger body sizes would complain about parts of their garment being too small and on the other hand, smaller men felt that some garment’s parts are too loose for them. Men reported issues with key body dimensions as they cannot find shirts that fit both their neck and arms (Sindicich & Black, 2011).

The apparel industry mainly manufactures female apparel that fits the current female ideal body shape (hourglass). As a result, consumers with body different shapes from the ideal body shape can experience fit problems. It is reasonable to conclude that an investigation exploring the relationship between men’s body shape and the current ideal male body shape may produce similar results. A number of studies acknowledged the need for body shape categorization to improve apparel fit (Ashdown, 1998; Devarajan & Istook, 2004; Petrova & Ashdown, 2008; Makhanya et al., 2014). However, the categorization of body shapes for apparel production must take into consideration many variables.

2.7 Diversity of Body Shapes in the United States

The figures of humans continue to change due to lifestyle, diet, migration, and the impact of trends on the ideal body shape (Apeagyei, 2010). The increase of minority groups and immigration to the U.S. has resulted in a more ethnically and racially diverse population (Martin, Hamilton, Osterman, Curtin, & Mathews, 2015). This diversity has been cited as one of the biggest challenges facing the U.S. apparel sizing system (Ashdown & Dunne, 2006). Presence of various ethnicities and demographic transformations in the U.S. population resulted in a
variety of body shapes (Ashdown, 1998; LaBat, 2007; Simmons & Devarajan, 2004). Therefore, the shape and proportion of the current U.S. population is different from the U.S. Army sample in 1940s. The large variation of ethnicities across the U.S. population has prevented the apparel industry from accommodating the fitting needs of all ethnicities and some marginal groups have reported encountering difficulty finding appropriate clothing that fit their style and preferences (Ahdown & Dunne, 2006).

There is a substantial body of literature on the variation of body shapes and their relationship to racial origins (Agbo & Igoli, 2015; Shin & Istook, 2007; Makanya et al., 2014; Manuel et al., 2010). Decades of studies on female body shapes confirmed diversity of body shapes within and between populations (Lee, Istook, Nam & Park, 2007; Makanya et al., 2014; Simmon, Istook & Devarajan, 2004).

Same body shapes have different characteristics between ethnic groups (Lee et al., 2007; Shin & Istook, 2007; Makanya et al., 2014). Findings from Lee et al. (2007), revealed different body shape proportion between U.S. and Korean women. Findings of the study by Shin and Istook (2007), confirmed the diversity of body dimensions among different ethnicities. Comparison of five different ethnic groups (Caucasian, African-Americans, Hispanic, Mexican, Asian) showed the smallest body dimensions in Asian and the largest body measurements in African Americans (Istook, 2007). Another study by Makanya et al. (2014) discovered that different body shape characteristics between African and Caucasian population. The body shape of consumers from ethnicity to ethnicity is different.

Therefore, racially and ethnically diverse consumers in the U.S. market resulted in diverse body shapes that are not targeted by the apparel industry and could not fit in the current
sizing system based on an ideal body shape. Hence, it is imperative to identify prevalent body figure characteristics in order to meet consumers’ needs.

### 2.8 Key Body Dimensions

Ethnic groups have been shown to vary on key body dimensions. Key body dimensions are defined as the body dimensions that have a high correlation with other body dimensions that are relevant to garment construction (ASTM, 2015). ASTM International has published a set of standards that indicate the exact location on the human body where these key measurements are to be obtained (ASTM, 2015). Correct selection of key dimensions is essential for body shape categorization (O’Brien & Shelton, 1941; Chun-Yoon & Jasper, 1996). According to McConville (as cited in Chun-Yoon & Jasper, 1996), key body dimensions must be “(a) convenient to measure, (b) be an integral part of the garment, (c) have a high degree of correlation with other dimensions important in design and sizing, (d) do not highly correlated with each other” (p.90).

It has been suggested to use a pair of key body dimensions, as there is no distinct measurement that represents both horizontal and vertical dimensions; therefore, one can serve as an indicator of horizontal measurements (such as height and length) and the other one as an indicator for vertical measurements (such as girth, depth) (Chun-Yoon & Jasper, 1996). Proper selection of the key body dimensions will lead to a better body shape classification. According to O’Brien and Shelton (1941), key body dimensions are the combination of body dimensions that have a strong relationship with other dimensions of the body. They used a pair of key body dimensions for classifying body figures, which had a low correlation between horizontal and vertical body measurements. For the vertical dimension, stature was selected as highly

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correlated to most vertical dimensions; and for horizontal dimension, weight was selected as was closely related to most trunk circumference (Chun-Yoon & Jasper, 1996).

Examination of fit and sizing of men’s business clothing currently available in the market revealed issues with key body dimensions. For instance, some consumers who choose their clothing based on key body measurements may not find suitable clothing that conform to their body shapes while those who choose their garment based on non-key dimensions may find garments with desirable fit in all areas (Sindicich & Black, 2011).

Older literature recommended various body dimensions according to the purpose of the study. Combination of hip circumference either with crotch height or leg outseam length was proposed for lower torso (cited in Chun-Yoon & Jasper, 1996). In another study, a combination of waist front length and shoulder breadth found to be the most statistically significant dimension for upper body and crotch height and hip circumference for lower body (Green, 1981). In the same study, a combination of bust circumference and crotch height was used for the whole body (Green, 1981).

Body dimensions and the shape of one’s body have been shown to influence the fit of clothing and a consumer’s preference for fit. Much research has pointed to issues with the size and shape of clothing available on the market today. To understand why these issues are present it is necessary to understand how the current sizing systems were developed and the inherent flaws that cause fit issues for the general population.

2.9 Development of a Sizing System

Sizing garments so that they will fit the consumer is one of the most difficult issues facing the apparel industry. Prior to the introduction of ready-to-wear apparel, tailors created
custom-fitted garments based on the individual’s measurement (Brown & Rice, 2014). After the industrial revolution, production of clothes that would fit each individual became practically impossible and costly (Ashdown, 1998). Therefore, today’s apparel industry uses sizing systems to create a range of sizes when producing ready-to-wear apparel. In order to reduce production costs, apparel is produced in the selection of sizes to fit the target population. According to Brown and Rice (2014), standardized sizes were established to enable the mass production of ready-to-wear clothing that conforms to a variety of body shapes and sizes of target consumers and their fitting preferences. Sizes are intended to fit a range of people in the population whose body measurements are included in predetermined standard dimensions (Ashdown, 1998; Workman, 1991).

The structure of sizing systems used today for ready-to-wear apparel originated from the proportional dressmaker’s drafting and grading systems used in the eighteenth century (Ashdown, 1998; Kidwell, 1979). A standardized garment sizing system is derived from anthropometric data of target consumers categorized by key dimensions, body measurements that are relevant to garment construction, into groups by size intervals (O’Brien & Shelton, 1941). Ashdown described standard sizing as “a method of classifying body shapes and providing size increment for the production of apparel” (Ashdown, 2007, p. 88), which illustrates that similar garment dimensions are classified in a same garment size group. This categorization is based on the assumption that all the members of each size group will share similar size, shape, length and width dimensions (Keiser & Garner, 2008). However, according to Mossiman’s shape analysis theory (1988) two individuals with different sizes may be categorized in a same body shape group. By applying shape analysis theory (Mossiman, 1988) to the categorization of body types,
it can be argued that all individuals in a same size category cannot be expected to have the same body types (Connell et al., 2006).

Sizing systems from different countries are developed based on the key body dimensions that are used to divide their population into size groups, such as height, or ratios between body measurements (Ashdown, 1998). According to Ashdown (1998), the goal of sizing systems is to provide the best fit for most consumers in the population and provide adequate variations that accommodate various body shapes and sizes while limiting the number of sizes. The number of sizes in sizing systems is important as adding more sizes increases the cost of manufacturing and production (Ashdown, 1988). Also, consumers may find it difficult to locate their correct size among a great number of sizes and shapes. Therefore, the challenge of a sizing system is to provide desirable fit for wide range of consumers while limiting the number of sizes (Ashdown, 2014).

In order to accommodate a broad range of measurements within the sizing system, the key dimensions are generally distributed evenly across the sizing systems. However, the growth of these ranges is proportional but not progressive (Ashdown, 1998). According to Shin and Istook (2007), “even growth between all sizes is not logical” (p. 136), since an adult does not get taller as he gets wider.

The standardization of men’s apparel sizing for the mass production of garments in the U.S. was initiated during the Civil War from 1861-1865. Measurements of soldiers were compiled into size charts and used as a basis for mass production of uniforms (Brown & Rice, 2014). Currently, the American Society for Testing and Material (ASTM) provides voluntary standards development system for male and female clothing in the US. According to Cooklin (1992), while women’s sizing systems are based on large scale anthropometric studies, men’s
standard sizing (ASTM D6240) has been solely based on data collected from military uniforms, which are outdated and do not represent the current population. Another limitation of men’s standard sizing is that it is based only on regular body shape (Shin, Istook, & Lee, 2011). The ASTM conducts a reviews of its standards every five years to make sure that the basic information and procedures are still current as volumes of standards are issued annually (LaBat, 2007). According to ASTM International updating of the anthropometric data the charts for men’s sizing were originally approved in 1998 and the last edition was updated on Feb 1, 2012. ASTM’s committee D13.55 is charged with monitoring and updating the charts (Keiser & Garner, 2008). However, the new standards published after the ASTM reviews in most cases are not based on new large anthropometrical studies, they are just revisions stemming from limited practices of a number of clothing companies and military data. As the ASTM data consists of manual measurements, a new extensive anthropometric study would be extremely costly and face several challenges (LaBat, 2007).

The Textile Clothing Technology Corporation (TC2), which is a non-profit organization, initiated extensive anthropometric studies using 3D body scanning internationally leading to large surveys referred to as SizeUSA, SizeUK, and SizeMexico. These studies were also supported finically by industrial partners. Studies and investigations conducted on the new anthropometric studies such as SizeUSA underscore the fact that current sizing standards are outdated and do not represent the body shapes of current populations (LaBat, 2007). In 2002, Simmons conducted a study to determine if ASTM sizing standards fit the current U.S. population with the use of Best Fit Software. This study concluded that the current sizing standard is outdated regarding the changes in lifestyles and influence of ethnic diversity since 1940s (Simmons, 2002). Comparison of drop value of the SizeUSA data with the ASTM D6240
revealed that the current population consists of a wider range of body shapes such as regular, big & tall, athletic, stocky, and portly (Simmons, 2002). However, the current men’s sizing system (ASTM D6240) is based on a regular body shape, an inverted triangle where the chest is larger than the waist. While, this study found that only 34% of the SizeUSA data would fit in regular menswear fitting category followed by 31% categorized as tall and athletic (Shin et al., 2011).

Although it is universally understood in the apparel industry that current sizing systems are flawed, improving them is a multi-step process and may be cost prohibitive for many brands. Additionally, brands have discovered they can increase profits and maintain a brand image by manipulating the size of a garment so there is reluctance to change as we will discuss in the following section.

### 2.10 Fit and Sizing Issue

The size label on a garment is intended to assist consumers in determining if a specific garment is suitable for them according to their body dimensions. Size labeling is classified based on sex, age, and/or body figure (Brown & Rice, 2014). However, in the US there is no law that requires the size placed on a garment to correspond to any standardized set of anthropometric measurements. Thus, different companies develop their own sizing systems to fit their own target market. This lack of standardization has permitted the marketing tool of vanity sizing. Vanity sizing is a tactic of clothing manufacturers, to increase their profits and sell their cloths by increasing the actual size of the garment, but labeling it as a smaller size (Aydinoglu, Krishna, 2012; Brown & Rice, 2014; Bubonia, 2014). Additionally, some brands are reluctant to change their current sizing for other financial reasons.
The number of sizes in sizing systems is important as adding more sizes results in increasing the cost of manufacturing and production. Also, consumers may find it difficult to locate their correct size among a great number of sizes and shapes. Therefore, the challenge of sizing systems are to provide desirable fit for a wide range of consumers while limiting the number of sizes (Ashdown, 2014). According to the ASTM (2012), the goal of the sizing system is to provide consistent sizes and size labels based on the anthropometric measurement of the current population to offer well-fitted garment and reduce the consumer’s confusion and dissatisfaction associated with apparel sizing.

The lack of a standardize size range that accommodates different body shapes can be easily understood by examining ASTM size charts. The current men’s sizing system (ASTM D6240) is based on an inverted-triangle body shape, where the chest circumference in all size categories is larger than the hip and waist girth; and hip circumference is wider than the waist. For example, in men’s size 34 the: chest girth = 34, waist girth= 28 ½, and hip girth= 33 ½, which illustrates the inverted triangular body shape. However, comparison of drop values of the SizeUSA data with the ASTM D6240 revealed that the current population consisted of a wide range of body shapes such as inverted-triangle, big & tall, athletic, stocky, and portly. The only study that could be found regarding menswear sizing system and fit issues was conducted in 2011 by Shin, Istook, and Lee. In that study they found that only 34% of the SizeUSA data would fit in inverted-triangle (regular) menswear fitting category followed by 31% categorized as tall and athletic (Shin et al., 2011). More investigation is needed to fill the huge gap in the literature, since apparel size categories and fit issues have not been investigated and documented for male population as broadly as they have been studied for women.

The men’s apparel sizing system currently used in the U.S. is based on the
anthropometric data that were studied over 7 decades ago that does not represent the current U.S. population (O’Brien & Sheldon, 1941). This data was inherently biased because the majority of participants were young and serving in the military, so they were not representative of the general population. Researchers widely acknowledge that the shape and proportion of the current U.S. population is different from the U.S. Army sample taken in the 1940s. Since that study the U.S. population has undergone dramatic physiological and demographic transformations (Ashdown, 1998; LaBat, 2007; Shin & Istock, 2007). With such variation many groups cannot find garments with appropriate fit as they are not considered in the sizing system.

There are different factors that contribute to consumer dissatisfaction with clothing fit: lack of a standardize size range that accommodates various body types, outdated sizing system, lack of standardize labeling and body measurements on hang tags (Ashdown, 1998), and lack of accurate grading methodology (Gribbin, 2014). One crucial factor that determines apparel fit is body shape. In reality, there exists a variety of body shapes within a specific nominal size, while the apparel industry produces clothing under the assumption that individuals would have similar body shapes when they have identical anthropometric measurements (Keiser & Garner, 2008). This assumption used in sizing systems is wrong as weight is distributed differently based on body types (Marshall, Jackson, Stanley, Kefgen, & Touchie-Specht, 2004). Body shape will determine where weight is distributed while ASTM measurement charts just consist of anthropometric data and do not provide any indication of how circumference measurements are distributed (Romeo, 2013). As a result, people may experience very different fit problems while having identical body measurements, simply because they have different body shapes (Brown & Rice, 2014; Vuruskan, & Bulgun, 2011).

Another issue which greatly affects the fit and sizing of clothing is grading methodology.
Grading is the increasing or decreasing of a master pattern at specific locations to create a range of sizes (Brown & Rice, 2014). Gribbin (2014) noted standardized sizes and pattern grading practices currently used in the industry are a major source of poor apparel fit. Grading of patterns to create a range of sizes contributes to poor fit because it assumes that proportionally increasing and decreasing of all body dimensions at the same rate when migrating from one size to another size can fit most of the population (Mullet, 2015). To accommodate a broad range of measurements within the sizing system, the key dimension is generally distributed evenly across the sizing systems. However, the growth of these ranges is proportional but not progressive (Ashdown, 1998) and Shin and Istook (2007) noted, “the even growth between all sizes is not logical” (p. 136), since an individual does not get taller as he gets bigger.

Fit and sizing issues are more apparent with clothing, such as blue jeans, evening gowns, and tailored suits, not one-size-fits-all items, such as wrapped clothing. Close fitted garments have demanding fit requirements as they are expected to follow the curvature and contour of the body and remain comfortable at the same time (Ashdown, 2014). One potential resolution to offer better apparel fit to any population with diverse body types may be found through technological advancement in the apparel industry (Vuruskan, & Bulgun, 2011). Technological development in apparel sizing and fit such as automated made-to-measure clothing is an innovative way to solve sizing and fit issues (Ashdown & Loker, 2010). Technological development, such as 3D body scanning and computer-aided design (CAD) programs for generating custom patterns can provide customization for the apparel industry (Ashdown & Dunne, 2006).

As discussed there are several reasons why consumers experience fit issues with the current clothing available on the market. In the US there are no laws regarding the sizing of
clothing, brands determine for themselves the size and shape of their target customer, the anthropometric data most brands base their sizing upon is outdated and flawed, and grading methodologies are inherently flawed. Often consumers must engage in a trial and error quest to find the brand which manufactures clothing that most closely fits their body shape and size.

2.11 Individual Brands Determine Fit Based on Target Customer

In the US most pants sizes are based on two measurements. The first number is width and the second number is length, which are commonly separated with an X or slash. Well-known brands in US use the waist size to get the width and length of inseam for the length measurements (Figure 2.11). The size of the waistband is usually indicated with letter W and the leg length specified with letter L. For example, if the size label on the pants shows 34/33 or 34X33, it means that the waist size is 34 inches and the leg length is 33 inches. In the following section the measurement differences between popular brands of men’s jeans such as Levi Strauss, Lee, 7 for all Mankind will be compared.

Figure 2.11. Levi’s visual guide for size selection, Levi Strauss Corporation, 2018
When comparing the size charts of different companies, two points are very noticeable: (1) inconsistencies of measurements between different brands; (2) The proportional changes of waist and hip girth measurements. It is worthy to mention that the smallest available size is different among the three mentioned brands. For example, the smallest Levi’s size, 26 refers to waist girth of 26.5” to 27” while the smallest available size in 7 for all mankind and Lee brands, size 28, refers to waist girth measurements of 28.5” and 27.5” to 28” respectively. On the other hand, the measurement specifics of the same numeral size numbers are different in the three brands. For example, the nominal size of 32 refers to a waist girth of 32.5”-33” in the Levi’s brand, while the same nominal size number, 32, indicates a waist girth of 31.5” to 32” in the Lee brand size chart.

It is also evident from all three size charts that there is a linear relationship between the change in the waist and hip girth measurements. For example, if the waist girth changes by one unit between two successive nominal sizes, the hip girth also changes one unit. This difference in girth between two successive nominal sizes changes to two units for both waist and hip at larger sizes. This linear relationship between the waist girth and hip girth is too simplified and do not represent the actual body shapes.

2.12 Body Shape Analysis

Prior investigation indicated that an individual’s body dimensions change every ten years (Lee, 2014 cited in Liu et al., 2016). In addition to variability of body shapes across times, the change of body figure within and between different body types has made the classification of body shape challenging (Connell et al., 2006). For years there has been ongoing dialogue concerning the need to analyze body shape as a way to increase fit satisfaction (Connell et al.,
According to Petrova and Ashdown (2008), classification of the body shapes of a population is an essential factor to achieve good apparel fit. Different body shapes result in different fit preferences (Alexander et al., 2005). According to Mossiman’s shape analysis theory (1988), an individual’s size and body shape are not related, which indicates that individuals within a size category do not necessarily have the same body figure.

The apparel industry recognizes body shape as a vital factor to achieve good fit as many companies provide clothing based on different body shapes. Zafu is an online service that helps consumers to find best fitting jeans from 70 top jeans brands. Zafu offers recommendations to consumers based on their answers on several questions regarding the fit issues they have with their jeans as well as questions about their body shape, size, and style preferences. Zafu reported that with their body-shape recommendation service, 94% of consumers had found their best fitting jeans (“Zafu.com helps women find their perfect-jeans”, 2006). The results from a comprehensive fit research performed by Archetype Solutions were combined with the results of further measurements and fit-quantified photographs of thousands of women by Zafu itself to form the online resource (“Zafu.com helps women find their perfect-jeans”, 2006).

As women have been receiving more attention and scholarly research and men’s fitting preferences are very limited. Therefore, in this section different methods that have been used to categorize women’s body shape will be examined. The advantage and disadvantage of each technique will be discussed to be able to choose the best methods to categorize men’s body shape in this study.
2.12.1 Body shape classification in academia

Various techniques have been proposed by researchers to classify body shapes for different applications. The following discussion presents some of approaches of women’s body shape analysis in academia. The three main body shape categorization systems that were identified in the literature (Petrova & Ashdown, 2008; Song & Ashdown, 2011) are as follows:

1. Proportions of front and/or side silhouettes, which was implemented by Douty (1968), Minott (1978), and Connell et al. (2006)
2. Proportion of body circumference measurements, implemented by Simmon et al. (2004), and Petrova and Ashdown (2008)
3. Principle components (PC) analysis, which was implemented by Salusso-Deonier, Delong, Martin, and Krohn (1985), Salusso-Deonier, Borkowski, Reich, and Goldsberry (2006), and Song and Ashdown (2011)

The first method determines the shape of individuals based on visual assessment. Connell et al., (2006) determined females body form based on visual shape analysis scale using 3D body scan data. The whole and component body shape assessment scale (BSAS) was developed based on existing literature (Douty, 1968; Minott, 1978). In the mentioned study, 42 women aged 20-55 years were scanned and nine scales for body shape assessment from front and side views were developed, including three whole body scales and six component body part scales. Whole body parts include: body build, body shape, and posture and body parts scales were as follows: front torso shape, hip shape, shoulder slope, bust shape, buttocks shape, and back curvature. The collective findings from all the nine body component measurements were utilized to identify the whole body shape of women under the study. The main drawback of this method was that only one view plane of each body was analyzed at a time, which is problematic as for example two bodies could have identical front views while having different side views (Petrova & Ashdown, 2008). According to Song and Ashdown (2011), visual body shape assessment, which based on comparing the width and depth from the side and front view are not
related to traditional pattern making techniques because traditional pattern making construction is based on circumferential and curvature measurements of the body.

In the second method, width and depth projections were combined for shape evaluation. This combination makes it possible to distinguish between two bodies with identical waist and hip widths, while having different waist and hip depths (Petrova & Ashdown, 2008). Simmon et al. (2004) developed a ‘Female Figure Identification Technique (FFIT) for Apparel ©’ software to categorize female body shapes. The researchers categorized female whole body shapes into nine categories based on the girth measurement ratio between bust, waist, abdomen, high hip, and hip. According to Song and Ashdown (2011) this type of categorization system has limitations because “bodies with the same circumferential proportion may differ in width/depth proportion, or in some other defining shape measurements” (p. 916). Petrova and Ashdown (2008) determined the lower body shapes as straight, medium, and curvy by the hip-to-waist circumference ratio to identify ease value that provide good fit for pants base on individual’s body shape.

The third method utilized a multivariate statistical technique to classify human body forms. Principle component analysis (PCA) is a multivariate data reduction technique, which reduces the number of variables by combining similar variables into new composite dimensions called PCs. An early use of multivariate statistics to categorize variations in body forms, was carried out in 1941 by O’Brien and Sheldon. They solely used PCA to select dimensions for bivariate classification (Salusso-Deonier et al., 1985). In the prior studies to their work, body measurements such as girths, lengths, and heights were acquired as independent variables to be used for the whole body shape analysis. They further categorized the independent variables as PC1 and PC2 groups referring to horizontal and vertical measurements accordingly (Salusso-
Deonier et al., 1985). A recent study categorized male’s upper body shapes using multivariate statistics (Shin et al., 2011), which will be discussed below.

2.12.2 Limited researches on males body shapes

The first significant body shape classification was made in the field of psychology by William Sheldon in relation to individual’s physiology and psychology (Sheldon, 1940). Although Sheldon was criticized in subsequent research for attempting to predict criminal or deviant behavior based on body shape, his initial work of categorizing basic body shapes is still widely used and respected. In his ground breaking research on body shapes in 1940, Sheldon photographed 4,000 male college students from front, back, and side view (Sheldon, 1940). The classification was based on the visual analysis of photographs. Inspecting somatotype photos led to three basic body shape categories: endomorph (short/fat), mesomorph (lean/muscular), ectomorph (tall/thin), as shown in Figure 2.12 (Sheldon, 1940). As the life styles and eating habits of people change across time, Johnson (1990) revised body shape classification of Sheldon by adding two more categories, ecto-mesomorphs and endo-mesomorphs that illustrate the current physical characteristics of individuals. As discussed before, categorization based on front, back, and side view suffers from the fact that the two view planes of each body cannot be analyzed simultaneously, which itself can be problematic as two bodies could have identical front views while having different side views (Petrova & Ashdown, 2008; Song & Ashdown, 2010).
The standard apparel sizing systems have categorized men’s bodies based on the chest-waist drop value. The sizing system created by the International Organization for Standardization (ISO/TR 10625:1991) categorizes men’s body shape into five different body types: Athletic (A), Regular (R), Portly (P), Stout (S), and Corpulent (C). The drop value ranges from 2.4-6.3 inches (6-16cm). The Athletic and Regular body types have a larger chest girth compared to waist circumference. On the other hand, the Portly and Stout body types have a larger waist girth than the chest. The Athletic body type (A) has at least 6.3 inches (16 cm) drop. The Regular body type (R), which has a larger chest girth than the wait, has at least a 4.7 inch drop value. The Stout (S) and The Portly (P) have at least a 2.4 inch larger waist girth than the chest size. In the Stout body type (S), the chest girth is approximately equal to waist size. The Corpulent (C) body type has at least 2.4 inches larger waist girth than the chest (Chun, 2007).
A 2011 study used multivariate statistical techniques to classify men’s upper body shape based on BMI and drops values (Shin et al., 2011). The SizeUSA men’s dataset was used for the purpose of categorization. Factor analysis was conducted with 25 body measurements (weight, chest, hip, waist, upper arm, elbow, across shoulder, calf, tight, center trunk, knee, armscye, neck, cross chest width, shoulder length, cross back width, ankle, crotch height, waist height, height, arm length, crotch length total, waist length front, waist length back, and shoulder slope) to create set of variables for similar items in the set. Four sets of factors were found: girth factor, height length factor, torso length factor, and degree factor. These factors were used for cluster analysis. Based on factor scores and cluster analysis, four different body shape categories were found: Slim Shape, Heavy Shape, Slant Inverted Triangle Shape, and Short Rounded top Shape (Figure 2.13. Four men’s body shape).

Slim Shape (SS) portrays tall and ectomorphic body with normal or lightweight range, which is leaner than other shapes. In this category men’s chest size is almost equal to hip size. This shape was characterized by height length and girth factors. Heavy Shape (HS) portrays
athletic or big & tall body categories, which is similar to a combination of mesomorphy and endomorphy. In this category men’s chest size is larger than the waist and the hip size. This shape was characterized by torso length and girth factors. Slant Inverted Triangle Shape (SITS) could fit into regular menswear fitting category, bodies with normal to slightly overweight range, which has a slight inverted triangle shape that falls between ectomorphy and mesomorphy. In this category men’s chest size is larger than waist size. This shape was characterized by height length, girth, and shoulder degree factors. Short Rounded Top Shape (SRTS) could fit into portly or stout menswear fitting category, which is similar to endomorphy with larger hip than waist. In this category both front and back waist lengths are shorter, but the crotch length is longer. This shape was characterized by girth and torso length factors (Shin et al., 2011). The result is categorized in table 2.1.

Table 2.1. Result of men's body shape group by Shin et al. (2011), N=3686.

<table>
<thead>
<tr>
<th>Body Shapes</th>
<th>Sheldon’s Classifications</th>
<th>Menswear Fitting Categories</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slim Shape (SS)</td>
<td>Ectomorphy</td>
<td>Tall, Athletic</td>
<td>31%</td>
</tr>
<tr>
<td>Heavy Shape (HS)</td>
<td>Endomorphy and mesomorphy</td>
<td>Big &amp; Tall/ Athletic</td>
<td>26%</td>
</tr>
<tr>
<td>Slant Inverted Triangle Shape (SITS)</td>
<td>Somewhat or not mesomorphy/ Somewhat or not ectomorphy/ Not endomorphy</td>
<td>Regular</td>
<td>34%</td>
</tr>
<tr>
<td>Short Rounded Top Shape (SRTS)</td>
<td>Endomorphy</td>
<td>Portly &amp; Stout</td>
<td>9%</td>
</tr>
</tbody>
</table>

In addition to factor scores and cluster analysis, four other values were also computed to analyze men’s upper body shape: BMI, differences between chest and waist girth, hip and waist girth, and hip and chest girth.
2.13 Quantification of Garment Fit

Fit of the garment is considered to be one of the curial factors in the quality of the clothing and consumer satisfaction. Various methods have been used to examine the fit of a garment in the design and production stage. Historically, live models and dress forms are used together to assess garment fit. Although live models are varied in body measurements and may not be perfectly symmetrical like dress forms they are assumed to reflect the shape and measurements of the brand’s target customer (Peñaloza, 2011). Live models, known as fit models, provide invaluable insight, as they can give comments about the poorly fitted areas based on the feel of the garment on their body. Pattern makers and designers use dress forms as they are consistent in measurements and available for use at any time, however, often they do not represent the actual shape of the human beings (Song & Ashdown, 2010). Given the fact that one fit model cannot represent the diverse body shapes of individuals in the population (Ashdown & Loker, 2010) researchers have identified different ways to evaluate fit. The methods of fit assessments are categorized to subjective and objective quantification.

2.13.1 Subjective fit quantification

Subjective clothing fit evaluation is based on the feedbacks from either consumer (Alexander et al., 2005; Bye & LaBat, 2005; Kim & LaBat, 2013; Pisut & Connell, 2007) or expert judge opinions (Kim & LaBat, 2013; Song & Ashdown, 2010; Song & Ashdown, 2012), or both (Kim & LaBat, 2013; Song & Ashdown, 2010; Song & Ashdown, 2012). There is not a unified definition of a well-fitted garment as the definition of fit is affected by various factors such as gender, age, size, trends, culture, style, individual’s perception of fit, and more (Pisut & Connell, 2007). Perception of fit varies from time to time and person to person and individuals have their
own standards for evaluating fit that may be different from traditional definitions of proper fit. For example, one person may prefer loose fitted pants while another person may prefer slim fitted pants. Subjective quantification of fit enables the apparel industry to understand fit from a consumer’s perspective (Sindicich & Balek, 2011).

However, understanding fit from a consumer’s perspective is complex. Since two external (social message: ideal body and fashion industry: fashion figure and sizing system) and two personal (body cathexis and physical dimensional fit of garment) influences have impact a consumer’s fit satisfaction (LaBat & DeLong, 1990). Due to the complexity of subjective fit assessment, researchers developed fit evaluation rating scales to collect consumer’s fit perception. For example, Yu et al. in 1998 (cited in Yu, 2004a) developed a fit evaluation scale for a men’s jacket as shown in Figure 2.14. Ashdown and Song (2012) used both participants and expert judges to evaluate the fit of block patterns developed for different body shapes using a 5-point scale at 12 body locations: waist ease, abdomen ease, hip ease, thigh ease, knee ease, crotch ease, front waist placement, back waist placement, crotch placement, hip placement, side seam placement, and inseam length.
Fit issues are judged based on subjective and qualitative assessments, while such approaches suffer from the ineffective communication and lack of precision and agreement on proper fit (Song, 2011; Yu, 2004b). Also, for consumers with limited knowledge about fitting terminology it is hard to verbalize their fit issues (Ashdown, 2007). In both qualitative and quantitative practices, the subjective evaluation is not capable of providing precise results due to dissipation of information through communication (Yu, 2004a). Therefore, assessment from an expert’s point of view is needed to shed light on the relation between the body and garment and address these issues. The evaluation process is expressed subjectively either through qualitative statements or quantitative scales. Therefore, the results of subjective evaluation are influenced by personal characteristics and experiences of the assessors (Fan, Hunter, & Liu, 2004).
2.13.2 Objective fit quantification

Objective evaluation of clothing fit is more accurate compared to subjective evaluation and provides more quantitative information (Yu, 2004b). The subjective methods of evaluating clothing fit tends to be inconsistent and inaccurate as they are highly influenced by personal criteria (Yu, 2004a). Thus, objective assessment is required to quantify the relationship between the garment and body. There have been several studies on fit issues to discuss the problems and provide logical approaches to address its complexities (Apeagyei & Otieno, 2006; Yu, 2004a).

Moiré topography is a non-contact technology that was used since 1980s. Yu (2004a) believed that the contact method of evaluation is not applicable as evaluating soft objects like clothing resulted in deformation. Shadow moiré topography is useful to capture the 3D form on a 2D fringe pattern to measure and evaluate clothing fit (drape, wrinkle, bagging) and body shape (Yu, 2004b). In 1998, Yu and his colleges used this technique to evaluate the fit of a jacket by placing a jacket worn by a mannequin close to a grid plate to obtain a sharp image of moiré fringe (Figure 2.15). The objective evaluation of the jacket shape was conducted by performing digital analysis of different sections, i.e. front, back, and side. The result which was a fringe pattern was further digitized, while the corresponding co-ordinates of each sectional profile were quantified with using fourth-order polynomial functions and root-mean-square data which were derived from body shape characteristics (cited in Yu, 2004b).
Technological developments in the apparel industry including three-dimensional (3D) body scanners provide more reliable objective fit evaluation. Wu et al., (2011) used objective evaluation to assess the virtual fit and the accuracy of a simulated garment produced in a commercial Computer Aided Drafting (CAD) system. Using statistical analysis enabled the researchers to compare the linear measurements of virtual and real skirts for fit analysis. Three-dimensional CAD systems provide different technical tools that can be used for fit quantification in both subjective and objective manners, once combined with visual verification of fit on the computer screen (Lim & Istook, 2011). However, according to Sayem (2017), “a true objective approach would be to consider the numerical values of fabric tension, stretch, and collision pressure of virtual drape of a simulated of garment to evaluate virtual fit not” only visual assessment based on the color map (p. 159). Sayem (2017) used the virtual prototyping and fit analysis technique to evaluate the drape behavior and fit of a men’s shirt. Technical tools of 3D CAD system were used for objective fit analysis of virtual shirts to identify ill-fitted areas and then modify the pattern for proper fit.

Lin and Wang (2016) used a statistical approach to objectively evaluate the fit of virtual clothes by examining the relationship between different body shapes and clothing. The vacant
space analysis was used at key position of the human body to assess clothing fit objectively. The vacant space is defined as “the ease space between the cross section of the human body and the clothing” (Wang, 2016, p.1915). To provide an assessment of clothing fit objectively, the fitting index \( F(\%) \), was calculated to indicate the vacant space area between the human body and the clothes. The vacant area can be calculated by the following equation:

\[
F(\%) = \frac{A_{clothing} - A_{Body}}{A_{Body}},
\]

where \( A_{clothing} \) represents the value of clothing area and \( A_{Body} \) represents the value of the human body area.

The objective techniques are popular for industrial applications as they provide views from different pattern constructions and methods of assembly and have minimum dependency on personal evaluations and experiences (Yu, 2004b).

2.14 Application of Body Scanning Technology in Sizing and Fit

It is quite safe to claim that the recent advances in computer technology and in particular 3D body scanning are the greatest recent developments in the field of clothing sizing and fit (Gill, 2015). If one refers to the manual methods of performing body measurements as the signatures of clothing industry through the 20th century, the 3D- body scanning technology on the other hand, is very promising and expected be widely used in product-development over the 21st century. The importance of 3D body scanning in sizing and fit practices is evident in recent works of researchers in analysis of sizing system (Ashdown, 2007), classification of body shape (Lee et al., 2007; Song & Ashdown, 2011; Shin et al., 2011), assessment of clothing fit in 3D environment (Lim & Istook, 2011; Sayem, 2017; Song & Ashdown, 2015).
In addition, by providing 3D point clouds, the 3D scanning process can deliver body avatars. The availability of body avatars allows for repetition of population body analysis during product development (Gill, 2015). The importance and effectiveness of 3D body scanning goes beyond its comprehensive set of body measurements as it significantly improves the understanding of the human body in relation to clothing (Bye, LaBat, & DeLong, 2006; Istook, 2008). The unique features of body scanning such as measuring point, length, surface, shape and volume are well beyond what other measurement techniques can deliver (Bye et al., 2006). The in-depth set of body measurements provided with 3D scanning techniques enables a comprehensive analysis of the body figure that would not be achievable through traditional methods (Gill, 2015). Scanning technology has enabled the classification of body shape from proportions of the scanned image (Song & Ashdown, 2011; Shin et al., 2011)

2.15 Three-dimensional Virtual Prototyping and Fitting Technology

Ensuring the fit of the garment before manufacturing is one of the major challenges of apparel companies (Clark & Wilhelm, 2011). Prototyping a garment using traditional 2D patternmaking is a time consuming and costly process as it includes drafting patterns, cutting fabric, assembling pattern pieces and finally shipping the garment to the client or fit model for assessing the fit (Clark & Wilhelm, 2011). Although prototype sample garments are produced from an inexpensive fabric, it still considered as a costly step in manufacturing (Ashdown & Dunne, 2006). Several iterations of the prototype sample may be needed to perfect the fit and style of the garment before manufacturing. This iterative process of consecutive prototypes can account for 4 to 6 percent of the total production expenses (Istook, 2011). The cost of a single physical prototype is estimated to range from $250 to $1,000 in addition to design and
development costs. Rejecting a style from the line means wasting all the embodied costs of physical prototyping (Clark & Wilhelm, 2011).

With the advancement of technology in the apparel industry, three-dimensional scanning and 3D garment simulation have become valuable tools for assessing garment fit (Song & Ashdown, 2015). The technological development in garment simulation can be used by the industry as a remote communication tool to evaluate clothing fit without making an actual prototype, which itself could lead to a more efficient decision-making process and quality (Yu, 2004b). Three-dimensional visualization without physical prototypes is a potential way to cut the cost of prototyping or rejecting a style (Ashdown & Dunne, 2006; Clark & Wilhelm, 2011; Salmon, 2014). As patterns can be generated automatically based on body measurements and visualized on computer-generated digital model (Lu, Wang, Chen, & Wu, 2010). Virtual try-on uses computer software to simulate a garment on a computer generated person called an avatar. It permits the designer to visualize and correct the fit of a garment without a live person trying on the item (Baytar & Ashdown, 2015). In addition to reducing the overall costs of production, this technology can cut the lengthy process of the designing and prototyping procedure by about 50% (Song & Ashdown, 2015). A 3D avatar is a three-dimensional fit model that can be created by either of the following approaches: a) synthesizing avatar by changing the parametric body measurements by the user to achieve a desirable body shape and size (Sayem, 2017; Lim & Istook, 2011); b) utilizing the 3D body scanning for determination of the user’s own actual avatar (Lim & Istook, 2011; Istook, 2011).

Most of the CAD systems provide 3D virtual clothing simulation software to test garment fit virtually: include the Modaris® by Lectra, V-Sticher™ by Browzwear, e-fit Simulator™ by TukaTech, 3D Runway Designer and 3D suite by Optitex (Sayem, 2017). The 3D garment
simulation enables consumers to try-on a garment on their own 3D avatar and evaluate the fit before shopping. One example of online apparel shopping applications is Bodymetric, which allow the users to try-on virtual garments with Microsoft Kinect camera technology at home on the television (Taylor, 2012; Aamoth, 2012). Another similar application is Filet, unlike the Bodymetric, which required the consumers to get their body scanned at the store, it enables consumers to create their own 3D avatar by entering the height and several pictures from an iPhone at different angles (Zakrzewski, 2014).

In terms of the accuracy of virtual fit, several researchers have examined the effectiveness of 3D garment simulation for evaluating fit (Kim & LaBat, 2013; Song & Ashdown, 2015; Sayem, 2017). Two separate research teams, Kim and LaBat (2013) and Song and Ashdown (2015), investigated the accuracy of virtual try-on technology by comparing the fit of real pants and virtual pants. In both studies the accuracy of the virtual fitting technology was rated moderately good. According to Kim and LaBat (2013), the overall appearance of the simulated pants was reported to be similar to the real pants as the hip shape, waistband and inseam position, and the length of the pants were described to be accurate by the participants. The main cause of dissimilarities resulting in a moderately good rating was inaccurate fabric representation. Sayem (2017) pointed out that this discrepancy resulted in not using any tension and pressure mapping tool. Song and Ashdown (2015) also reported that the simulated pants “represented less ease than the actual pants, and the software could not express small stress and folds from slight tightness and looseness” (p. 328). Visual assessment alone does not provide adequate information to evaluate the fit of a virtual garment and objective fit evaluation is needed to get enough clues to assess the state of the simulated garment (Sayem, 2017).
In terms of 3D avatar, different studies examined the accuracy of synthesized avatars and direct avatars (Lim, 2009; Lim & Istook, 2012; Jevsnik, Pilar, Stjepanovic, & Rudolf, 2012). Lim (2009), examined the accuracy of virtual garments on direct avatar and manual avatar. Findings indicated that the manual avatar could not exactly represent the actual body shape compared to the direct avatar. This discrepancy in avatars’ shape were also shown in the mechanical behavior of the virtual fabric. Comparison of the virtual garment to the real and manual avatar with the actual garment indicated that the virtual garment on the real avatar was the most similar to the real garment and provide more realistic representation of fabric drape and fit compare to the manual avatar. It was also found that the manual avatars of different body shapes (oval, rectangle, and spoon) were different from the direct avatar. Therefore, the researcher suggested that “the direct avatars are required to be used for many different body shapes” (Lim, 2009, p. 201). In another study, the fit of the virtual jacket prototypes on the parametric avatars and real avatars were examined. Large discrepancy was found between the fit of the virtual jacket on a manual avatar and a scanned body model (direct avatar). Those discrepancies were found to be smaller between the real made prototype and virtual jacket on the direct avatar (Jevsnik, et al., 2012). Both aforementioned studies concluded that the virtual try-on provides useful and realistic virtual prototyping of garments, which was also asserted for virtual prototyping of garments in a sitting position on sitting real body avatar (Rudolf, Cupar1, Kozar, & Stjepanović, 2015).

Wu et al. (2011) examined the accuracy and validity of 3D garment simulation by comparing a virtual skirt with a real one. Fabric properties of 20 different samples were measured in standard laboratory and then were used for accurate garment simulation. It was concluded that the 3D garment simulation is accurate as 18 out of 20 simulated skirts were
statistically similar to the real ones. There are several technical tools available within 3D CAD systems that help to simulate garments accurately, such as tension, stretch, pressure, and ease mapping tools (Sayem, 2017), which were not utilized by any of the above mentioned studies.

The current research used this approach to evaluate the fit of simulated jeans for different body shapes on direct avatars. It is now possible to review and verify the clothing fit and its correctness even before the production stage using virtual fit. Implementing virtual fit would result in better communication and reduction in product development time (Yu, 2004b; Ernst, 2009).

2.16 Mass Customization and Automated Custom Clothing in the Apparel Industry

The RTW clothing system is unable to provide well-fitted clothing that fit infinite sizes and various body shapes in the population. Therefore, today’s apparel industry is switching from a conventional mass production (ready-to-wear) to a mass customization system (Yang & Zhang, 2007). A broad definition of mass customization is “the mass production of customized good” (Istook, 2002, p. 61). Mass customization is defined as a system that use technologies and flexible process to satisfy an individual’s wants and needs at a cost near a mass production (Silveira, Borenstein, & Fogliatto, 2001). Technological development in the apparel industry allowed manufacturers to adopt a mass customization strategy to improve the fit of ready-to-wear apparel (Ashdown & Dunne, 2006). Some companies only focused on customizing the design and style of their products, such Polo Ralph Lauren, NikeiD, Timberland. For instance, Polo Ralph Lauren, enable the consumers to personalize their polo shirt by customizing: monograms, color of the pony, color of the shirt, add initials with desirable color and font (Ralphlauren.com).
There are some apparel firms that offer customized fit in addition to the design and style. Levi Strauss & Co. was the first large company that focused on both fit and style of jeans for each consumer. Levi’s first mass customized jeans introduced in 1944 as the “Personal Pair”, then marketed as the “Original spin” in the second iteration. Levi’s used digital technology to create customized jeans that fit an individual’s proportions. Consumers were able to customize their jeans by choosing the style (classic, low-cut, or relaxed), color, leg opening (tapered, straight, boot cut, flare, or wide), and the fly (either zip or button) on the computer screen. Custom fit was provided by taking three body measurements (hip, waist, and inseam) of consumers at the store. Jeans fit was determined by trying on one of the 242 samples that were kept in the store. Therefore, the salesperson could adjust the right fit based on the consumer’s preferences. Then the order was sent to the factory via the Internet to read consumer’s choice by CAD machines and further the pattern pieces are cut using automated cutting. Then, the jeans were manufactured and shipped to their home within two to three weeks. (“How Levi Strauss & Co. Puts an Original Spin on Mass Customization”, 1999). In 2004, the whole program was shut down to lower production costs. Later in 2010, Levi’s reopened its mass customization program under a new name called “Curve ID”. The two specific characteristic of the new program, which made it different from the Original Spin were as follows: a) the consumers could order their customized jeans on line (not only in a store); b) the customization was based on the body proportion instead of size (http://www.levistrauss.com/wp-content/uploads/2010/08/Levis-Brand-Introduces-Revolutionary-Fit-System-that-Focuses-on-Shape-Not-Size.pdf).

Other retailers have installed 3D body scanners and CAD systems for made-to-measure process purposes (Chen, 2006). Brooks Brothers uses a 3D body scanner at their retail store in New York City to collect consumers’ measurements to offer customized suit. Consumers choose
parameters such as style, fabric, and design from a user-friendly computer while consulting with a sales professional about fit preference details. Finally, the 3D body scan measurements for each individual consumer are utilized to produce personal patterns. The whole process results in a high degree of fit satisfaction due to its producing a pattern that addresses the individual’s needs (Haisley, 2002).

Land’s End, JC Penney, and indiDenim launched their online mass customization program in 2004. They used a self-measurement strategy to provide customized shirts, jeans, and chinos. Consumers typed in their measurements, like height and weight, in company’s website. They also entered other variables like proportion of thigh and hip. Then a computer program, Archetype Solution, analyzed the data to calculate the ideal dimension for pants (Khan, 2002). A software program created individualized pattern in a few minutes based on consumer’s body size by comparing consumer’s input to an extensive database of typical sizes (Schlosser, 2004). According to Land’s End, when the consumers are given the choice, 40% of them would prefer a customized garment as compared to the standard-size equivalent. Similarly, the number of the consumer’s reorders of the Lands’ End customized clothing were significantly higher than consumer’s reorders of standard-sized clothing (Schlosser, 2004). It is noteworthy to mention that JCPenny and QVC suspended their custom clothing productions. On the other hand, Lands’ End also stopped their custom pants production and only kept their men’s custom dress shirts. Setting up a successful custom fit system requires reliable and accurate body measurements, while collection tool for custom fit mass producer companies is consumer’s self-measurements, which is reported to be inaccurate by 2 ¼ of an inch (Ashdown & Dunne, 2006). Song and Ashdown (2012), postulated that the termination of custom pants production can be linked to the issues in the automation process while the actual reason was not disclosed.
2.16.1 Made-to-Measure systems

The mass customization system is a promising way to solve fit problems and produce well-fitting garments according to consumer’s need (Ashdown & Dunne, 2006). Advanced technologies in the apparel industry such as, 3D body scanning for fast and accurate body measurements, computer-aided design (CAD) for generating customized patterns for individuals made customization feasible for manufacturers to meet the needs of each consumer (Ashdown & Dunne, 2006; Lim & Istook, 2012). The fundamental part of mass customization is made-to-measure (MTM) apparel pattern systems, which take into account consumers’ needs to produce customized individual patterns (Yang & Zhang, 2007). Advanced computer-aided design (CAD) pattern-making systems enable the apparel manufacturers to develop complex patterns and grade rules quickly and accurately (Ashdown & Dunne, 2006).

Sophisticated automated CAD programs, which made customization a viable option to produce apparel products that fit individuals based on their body measurements are: Optitex, FitNet to Lectra system, AccuMark Made-to-Measure of Gerber Scientific, and MtM of Assyst (Istook, 2002, Lim & Istook, 2012). Although the apparel industry has technological development as a viable option for mass customization these technologies require advanced knowledge and skills in both apparel development and computer software use. For instance, CAD alteration systems for modifying a pattern to conform to an individual’s body shape and size requires a significant amount of knowledge in garment design, construction and grading as well as understanding how the software thinks (Istook, 2002).
2.16.2 Challenges faced in implementing automated apparel design patternmaking

Implementing advanced technology and automation is a promising way to improve apparel fit as they enable manufacturers to offer products to the consumer based on their wants and needs (Apeagyei & Otieno, 2006; Istook, 2002). As these technologies are in the initial experimental (or development) stage, generating clothing with perfect fit for each individual is still not accessible (Apeagyei & Otieno, 2006; Song & Ashdown, 2012). According to Istook (2002), commercial CAD softwares are complicated at the same time require a practical experience that is not easy to acquire.

CAD systems were initially adopted for traditional manual methods and not as a means to improve apparel fit and design innovations (Istook, 2002). Technological developments in the realm of information technology have resulted in a new way to use CAD systems for design and product development (Apeagyei & Otieno, 2006). Over a decade ago, Ashdown and Dunne (2006) investigated the readiness of current technologies for producing custom-fitted clothing and the difficulties to set up a custom apparel patternmaking process. Using 3D body scanning and CAD patternmaking systems (FitNet of Lectra) to gather body measurements and develop patterns, they compared fit of customized and non-customized jackets. In the first prototype jackets that were constructed based on RTW standards, only one of the prototypes fit well, two had poor fit and three were marginal. It took three successive modifications of garments, which addressed fitting issues such as: the reliability of body measurement data; the accuracy of body chart data; and the issue of fit preferences; to be able to offer proper fit to seventy percent of the participants (Ashdown & Dunne, 2006). With only 70% fit satisfaction in custom-made jackets, it can be concluded that even custom-made patterns cannot provide perfect fit for consumers (Song & Ashdown, 2012).
Song and Ashdown (2012) noted that in the collaboration they had with two global sportswear companies to create custom-made jackets, they could not achieve perfect fit for the participants with body shapes different from the fit model’s body shape. When the hip measurement was set as the primary measurement to automatically select the closest standard graded pattern, the fit at the bust was poor. In contrast, when bust was selected as the primary measurement to choose base pattern, the fit at the hip was poor (Song & Ashdown, 2012).

One solution to generate customized clothing with perfect fit is to initiate alternation process from different patterns for various body shapes, rather than starting from a single block pattern. Song and Ashdown (2012) improved customization by developing a set of basic patterns for three lower body shapes (curvy, hip tilt, straight) for women. They found that incorporating body figure information to generate custom-made clothing provided better fit.

Overall, previous literature on custom patternmaking processes showed that there are different factors that influence the process of generating custom patterns, such as: accurate body measurements, reliable body size charts according to target market, personal fit preferences, and accurate graded pattern to select as a base pattern for alteration (Ashdown & Dunne, 2006, Song & Ashdown, 2012).

2.16.3 **Computer-aided patternmaking system for mass customization**

There are several CAD programs for generating automated custom patterns from body measurements. Four methods have been identified for computer-aided custom pattern generation: 1) creating multiple sets of patterns that fit various body shapes by the traditional pattern making and grading process; 2) using a traditional pattern drafting method to automatically generate patterns based on body measurements; 3) Unwrapping a 3D
representation of a garment to make a 2D pattern shape; 4) selecting the closest-fitting pattern from traditionally graded pattern and applying automated alteration to custom fit the pattern (“Made-to-measure”, 2011).

In the fourth method, the software chooses the close-fitting pattern by comparing an individual’s primary body measurements with company’s body size chart. The base pattern was modified based on alteration rules. These rules themselves, were made by considering the differentiation between the individual’s and the manufacturer’s standard body measurements. Then, the alteration rules apply to the base pattern at the identified critical locations. The final pattern generates by merging the full set of alternations (Ashdown & Dunne, 2006; Song & Ashdown, 2012). The programs that create custom patterns in this way are: FitNet by Lectra Systems, AccuMark MtM by Gerber Scientific, and made-to-measure by Assyst Bullmer (Istook, 2002). Modulate by Optitex does not require the body size table and alteration rules. The program changes the base pattern parametrically based on a set of defined dimensions (Istook, 2002; Song & Ashdown, 2012).

2.17 Summary

The Theory of Inventive Problem Solving (TRIZ) was used as a theoretical framework for this study to find contradictions and problems that prevent the apparel industry from providing well-fitted garments. According to the literature, there are different issues that contribute to apparel dissatisfaction: (1) using outdated anthropometric data and the lack of current anthropometric measurements that reflect the size and body shapes of the current population (Ashdown & Dunne, 2006; Ashdown, 2014); (2) lack of accurate pattern grading.
methodology for mass production; (3) ASTM does not consider body shape of consumers in developing men’s size chart.

Fit is considered a crucial element of clothing quality and consumer satisfaction (Brown & Rice, 2014; Song & Ashdown, 2010; Workman, 1991). One factor in clothing fit satisfaction is the relationship between the garments and body shape (Makhanya et al., 2014; Shin & Istook, 2007; Sindicich & Black, 2011). However, examination of ASTM measurements charts shows that the body shape factor was not considered in developing sizing system, and size charts were developed based on the regular body shape do not consider any information regarding consumer’s body shape (ASTM, 2012). Therefore, knowledge of body shape is necessary to solve fit problems and produce well-fitting clothing that meets the wants and needs of consumers.

Although body shapes are not directly incorporated in current pattern-drafting methods, garment shapes and body shapes are correlated (McKinney, Gill, Dorie, & Roth, 2016). According to Connell et al. (2006), “body shape analysis is a logical theoretical underpinning for the development of apparel sizing that will fit well” (p. 81). Therefore, knowledge of body shape is necessary to draft a pattern that will fit consumers properly.

2.18 Research Questions

Based on the Review of Literature presented, the researcher investigated the following research questions:

RQ1: How are fit issues related to each body shape group?

RQ2: What is the relationship between men’s body shape and shape of the block pattern?
RQ3: How does the shape of the basic blocks created for each body shape compare to one another?

RQ4: Can the fit needs of more than one men’s body shape be accommodated by the same/single shape pattern block?

RQ5: Does the shape driven block provide a better objective fit than the block created from standard methods?
CHAPTER 3. METHODS AND PROCEDURES

The purpose of this study was to improve the fit of men’s jeans by categorizing their body shape and investigating the need to have a different base pattern shape for each body shape. This chapter contains the research design, sample selection, and data analysis that was used for the study. A quantitative research design was used to categorize the body shape of men aged 18-35; and a block pattern was developed with desirable fit for each body shape group. The blocks were examined to uncover if a single block can accommodate the fit needs of two or more men’s body shapes. For the purposes of this study the definition of quantitative research, which was developed by Aliaga and Gunderson (2002) is adopted: “explaining phenomena by collecting numerical data that are analyzed using mathematically based methods (in particular statistics)” (p.205).

3.1 Sample

The data set for this study was a random selection of 1420 male body scans, aged 18-35, that were part of the SizeUSA dataset. The original SizeUSA dataset is a random sample consisting of 10,000 subjects who were scanned using [TC]\(^2\) three-dimensional body scanners in 12 cities across the nation. For use in this research, the researcher purchased the scans from the Size USA 3D body scanning anthropometric database after signing the agreement form (see Appendix A). The purchased data was received as an Excel spreadsheet with demographic information, weight, height, the location of the scan (city and store) and 200 body measurements. The OBJ files containing the 3D data cloud for each scan were also provided.
For reliable body shape categorization, only those participants with a BMI of less than 30 were used in the classification analysis. The rationale behind this decision was to exclude obese participants, as the current software in use with the automatic 3D body scanners may produce errors in identifying landmarks and provide inaccurate measurement for nonstandard body shapes (Ashdown & Dunne, 2006; Han, Nam, & Shin, 2011). Interpretation of BMI based on the Center for Disease Control (2015) identifies individuals with BMI greater than 30 as obese.

3.2 Data Analysis Procedures

The data analysis for this study was adapted from Song and Ashdown (2012). Their model was modified to adapt it to mass customization by: (1) using random rather than purposefully selected participants; (2) Utilizing actual 3D avatars of fit models rather than fitting on a live person. These modifications reflect the challenges facing the industry in the implementation of mass customization; the customer’s size and shape are unknown, and the garment must be fitted on a computer-generated avatar of the customer using virtual simulation software (Song & Ashdown, 2012).

The data analysis took place in three phases:

- Phase 1: Statistical analysis was used to categorize lower body shape participants
- Phase 2: Develop basic block pattern for each body type:
  - Phase 2.1: A basic pants pattern block was drafted for one representative sample (fit model) from each identified body shape. Optitex pattern drafting and Virtual Simulation software was used to create the block and dress the avatars.
- Phase 2.2: Objective virtual fit analysis: drafted basic pants blocks were analyzed to identify and alter ill-fitting areas.
- Phase 2.3: finalize shape-driven basic block patterns by comparing the block patterns of each body shape with a control pattern that was developed based on current ASTM measurements.

- Phase 3: Validation of the use of the basic pattern block was conducted by comparing pants made from a single basic block with pants made from a shape-driven block by using 3D virtual technology on three representative men in each group (fit testers).

The fit models (in phase 2) for each body shape category were selected based on the average values of factors that were used for body shape classification. On the other hand, due to a lack of accurate grading methodology, the researcher decided to intentionally avoid any grading practice. This means that the fit testers (in phase 3) for each body shape were selected such that they had the same waist measurement as the fit models.

### 3.2.1 Phase 1: statistical analysis for body shape categorization:

For inclusion in this study BMI was calculated using the formula \(= \frac{\text{weight in pounds}}{\text{height in inches} \times \text{height in inches}} \times 703\) (Center for Disease Control, 2015). The participants with a BMI less than 30 was selected for body shape categorization analysis using IBM SPSS 22.0. The men’s upper body shape categorization method of Shin, Istook, and Lee (2011) was employed to classify men’s lower body shape. In this method, 15-20 lower body variables resulting from the SizeUSA 3D body Scan measurements were characterized using factor analysis to find influential and independent lower body shape factors. This was followed by a
cluster analysis, which itself would lead to identify the different body shapes that exist in the sample. To define the lower body shapes, body scans of each participant was used to choose measurements that are related to lower body shape analysis. These initial variables to be fed into factor analysis will be selected according to the following criteria:“(1) selection of front and back arc, widths, and front/back depths in order to categorize both the silhouette and profile of the lower body, instead of limiting to the more common ratios or drops of girth measurements, (2) measurements chosen for their usefulness for application to pants pattern making” (Song, 2011, p. 55).

3.2.2 Phase 2: develop block pattern for each body type

The test jeans style was a pair of jeans with straight leg and hem with fly zipper at the center front and a waist band at the natural location of the waist as shown in Figure 3.1. The reason for choosing this basic style was that it can serve as a base pattern to develop other styles. The virtual jeans were made from 100% cotton to represent the classic denim jeans and prevent stretching, which helps to judge the fit of the pants. For realistic drape simulation, a set of physical and mechanical properties of fabric were adjusted in the Optitex. The fabric parameters were entered manually using the Manual Edit Option (Figure 3.2).
The pants block patterns in this study were drafted in Optitex 2D/3D based on instruction for jeans from *Patternmaking for Fashion Design* book (Armstrong, 2005, p. 557). The required measurements for drafting jeans and the corresponding measurements in PDF format of body scanner output are listed in Table 3.1.

Table 3.1. Required measurements for drafting block patterns using Armstrong’s instructions and their counterparts in SizeUSA dataset

<table>
<thead>
<tr>
<th>Armstrong</th>
<th>SizeUSA dataset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waist Circumference</td>
<td>Waist girth</td>
</tr>
<tr>
<td>Total hip circumference</td>
<td>Hip girth</td>
</tr>
<tr>
<td>Front hip measurement</td>
<td>Front Hip girth</td>
</tr>
<tr>
<td>Back hip measurement</td>
<td>(Hip girth – Front Hip girth)</td>
</tr>
<tr>
<td>Crotch depth</td>
<td>Outseam Minus Inseam</td>
</tr>
<tr>
<td>Outside leg measurement</td>
<td>Outside Leg Length</td>
</tr>
<tr>
<td>Inside leg measurement</td>
<td>(Outside Leg Length - Outseam Minus Inseam)</td>
</tr>
</tbody>
</table>
3.2.3 Objective virtual fit analysis

The fitting process of the jeans was assessed virtually using Optitex 3D on virtual fit model as follows: 1) upload the actual 3D avatars of fit model that was scanned by SizeUSA; 2) pair the seams of the pattern and stitch the pattern pieces virtually; 3) position and curve the pattern pieces around the virtual model; 4) simulate virtual jeans; 5) assess the fit of the jeans using the tension map tool: a colored map illustrate the amount of tension, stretch and distance between fabric and the body, which helped to find areas experiencing fit issues.

Fit of the patterns was assessed visually on the virtual model (or scanned model) using the tension map tool, color indicator, and add circumference measure tool. The tension level is
scaled using a color spectrum, starting from blue, which refers to minimum tension, going through green and ending in red as the maximum tension color icon. The technical parameters such as physical tension (gf/cm), stretch (%), and collision pressure (dyne/cm²) on the virtual jeans were analyzed for each and every pairs of patterns. The amount of physical tension influencing the cloth were analyzed in three ways: tension XY (fg/cm), tension X (fg/cm) in warp direction along the baseline of each piece, and tension Y (fg/cm) in weft direction perpendicular to the baseline of each piece. The amount of stretch of fabric, which is the differences between 2D (pattern) and 3D (body) dimensions, was also analyzed in three ways: stretch XY (%), stretch X (%), and stretch Y (%). Additionally, the collision pressure (dyne/cm²), which explains the distance between the virtual fabric and virtual model were analyzed. After inspecting the preliminary virtual fit any ill-fitted areas of the pants were altered to make a fitted jean that conformed to the body shape of the model as “measurements alone do not reflect the total body shape” (Beazley & Bond, 2003, p. 25).

Once the proper fit was achieved for all the body shape groups, the modified patterns were trued and used as the final shape-driven block pattern for each body type group. The shape-driven block patterns were superimposed and compared to address the following research questions:

RQ1: How are fit issues related to each body shape group?
RQ2: What is the relationship between men’s body shape and shape of the block pattern?
RQ3: How does the shape of the basic blocks created for each body shape compare to one another?
3.2.4 Phase 3: validation of shape-driven block

The purpose of phase 3 was to validate the developed shape-driven block pattern. The appearance and fit of pants simulated with the shape-driven block pattern for a specific body shape category were compared on three fit testers from each body shape. Also, simulated pants developed based on current ASTM measurements on a fit tester from the same body shape category were compared with virtual pants of the three fit testers. Totally nine fit models (3 body shape group × 3 fit testers) were chosen and twelve pants (3 body shape group × 4 virtual pants) were simulated for fit validation of the developed shape-driven block (Table 3.2). Therefore, four simulations were conducted:

1. Two simulations on the fit tester of the same body shape group: one with shape-driven block pattern and one with the pattern developed based on ASTM body measurements.
2. Two simulations using the shape-driven block pattern on two fit testers from different body shape group, other than the shape-driven block pattern, with the same waist measurements.

The screenshots of both single block pattern and shape-driven pattern were included in the result section to address the following research questions:

RQ 4: Can the fit needs of more than one men’s body shape be accommodated by the same/single shape pattern block?

RQ 5: Does the shape driven block provide a better fit than the block created from standard methods?
Table 3.2. The simulations performed on fit testers during the validation phase

<table>
<thead>
<tr>
<th>Body Shape Groups</th>
<th>1st simulation</th>
<th>2nd simulation</th>
<th>3rd simulation</th>
<th>4th simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>Pants simulated with the shape-driven block pattern of group A on a fit tester from the same body shape group (group A)</td>
<td>Pants simulated with the single block pattern (ASTM) on the same fit tester from group A</td>
<td>Pants simulated with the shape-driven block pattern of group A on a fit tester from group B</td>
<td>Pants simulated with the shape-driven block pattern group A on a fit tester from group C</td>
</tr>
<tr>
<td>Group B</td>
<td>Pants simulated with the shape-driven block pattern of group B on a fit tester from the same body shape group (group B)</td>
<td>Pants simulated with the single block pattern (ASTM) on the same fit tester from group B</td>
<td>Pants simulated with the shape-driven block pattern of group B on a fit tester from group A</td>
<td>Pants simulated with the shape-driven block pattern group B on a fit tester from group C</td>
</tr>
<tr>
<td>Group C</td>
<td>Pants simulated with the shape-driven block pattern of group C on a fit tester from the same body shape group (group C)</td>
<td>Pants simulated with the single block pattern (ASTM) on the same fit tester from group C</td>
<td>Pants simulated with the shape-driven block pattern of group C on a fit tester from group A</td>
<td>Pants simulated with the shape-driven block pattern group C on a fit tester from group B</td>
</tr>
</tbody>
</table>
CHAPTER 4. RESEARCH FINDINGS AND DISCUSSION

The overall purpose of this study was to investigate the need to have different pants base block patterns for each body shape. More specifically, the goal of the study was improving the fitting of male’s jeans by categorizing the body shape of males aged 18-35 and develop basic block patterns for each identified body shape group. After examining the literature and identifying different issues that lead consumers to experience fitting issues with pants currently available on the market; it was revealed that the knowledge of body shape is crucial to draft a pattern to fit consumers properly. According to the Theory of Inventive Problem Solving (TRIZ) the next stage is to solve fit problems related to body shape issues and improve pants fit that meets the wants and needs of consumers. This chapter covers identified problems and presents research findings while answering the five research questions.

The findings of this study are useful for both academia and industry and: (1) provides apparel manufacturers vital information needed to manufacture bottom-wear for men that conform their body shapes with proper fit; (2) fills a gap in the literature regarding men’s lower body shape and its influence on achieving proper fit in bottom-wears.

4.1 Sample Selection

The purchased SizeUSA data contained a full set of measurements and demographic data for 1,820 men and 1,926 3D avatars of men aged 18 to 35. The data set was sorted to contain only those subjects that had both body measurement and demographic information with corresponding 3D avatars. This resulted in a complete data set that included demographics including height and weight, body measurements, and 3D avatars for 1,763 subjects. Based on
the CDC interpretation of height to weight ratio, individuals with a BMI value greater than 30 are classified as obese (Center for Disease Control, 2015). As a result, the BMI value of 30 was positioned on 80th percentile of the SizeUSA data for the subject pool of 1,763 individuals (Table 4.1). Subjects with BMI’s at or above the level designated as obese were excluded from the final subject pool. This resulted in a final subject count of 1,420 men between the ages of 18 and 35 who were within the normal body weight for their height and for which a complete set of demographics, body measurement, and 3D avatar data set were available. This set of 1,420 subjects became the subject pool for this research.

Table 4.1. BMI distribution of subjects aged 18-35 in SizeUSA data

<table>
<thead>
<tr>
<th>Percentile</th>
<th>25th</th>
<th>50th</th>
<th>75th</th>
<th>80th</th>
<th>90th</th>
<th>95th</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI</td>
<td>22.81</td>
<td>25.39</td>
<td>29.06</td>
<td>30.11</td>
<td>33.42</td>
<td>36.76</td>
</tr>
</tbody>
</table>

### 4.2 Sample Characteristic

A total number of 1420 subjects were included in this study. The basic demographic information of subjects is shown in Table 4.2. The majority of subjects were aged 18-25 (n= 840, 59.2%), and the rest were aged 26-35 (n= 580, 40.8%). In term of ethnicity, Caucasian subjects comprised 45.2% (n= 642), non-Hispanic black 15.5% (n= 220), Mexican-Hispanic 10.4% (n= 148), Asian 10% (n=142), non-Mexican8.9% (n=127) of the subjects. In terms BMI, the majority of subjects had normal BMI (n=795, 56%), with 42.1% overweight (n=598) and about 2% (n=27) underweight.
### Table 4.2. Demographic characteristics for the sample (N=1420)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Number of Subjects</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
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*Note.* Height is grouped based on The American Society for Testing and Materials standardize size for men D6240 (2012).

*Note.* BMI is interpreted using standard weight status categories, published in The Department of Health and Human Services Centers for Disease Control and Prevention CDC, About Adult BMI (2017).
4.3 Phase 1: Body Shape Classification

4.3.1 Measurement selection

Measurements chosen for the body shape classification were selected based on: (1) measurements that are useful for drafting pants blocks, (2) selection of girth and length measurements that define the silhouette and shape of the body. Therefore, the following measurements (Figure 4.1) were selected for the initial factor analysis: full girth drop (hip to waist, hip to top hip, top hip to waist), front/back arc (front hip to waist, front top hip to waist, front hip to top hip, back hip to waist, back top hip to waist, back hip to top hip), height (waist to hip height, waist to abdomen height, waist to crotch height), height proportion (waist to hip height / waist to crotch height, waist abdomen height / waist to crotch height), depth (distance between abdomen prominence minus buttocks prominence point), angle (buttocks angle).

**Figure 4.1. Initial body locations for the EFA analysis**
4.3.2 Verification of exploratory factor analysis (EFA) assumptions

Prior to performing the EFA several statistical assumptions needed to be checked: (a) the data screening, (b) the extraction (factor analytic) method, (c) the factor retention method, (d) the factor rotation method, and (e) the factor loading cut off (Howard, 2016).

An initial EFA test was performed with 18 items using the SPSS 22.0 to determine if the dataset was suitable for the EFA analysis. In the initial EFA, the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy was not provided in the SPSS output as the determinant score was zero, indicating the selected measurements had an issue of multicollinearity. Meaning that the initial variables, which were fed into EFA were highly correlated. To locate the variables responsible for multicollinearity, the bivariate correlation analysis was performed. In the first round of the investigation, the variables with high correlation values ($r > 0.7$) were singled out (Table 4.3). The following are the seven identified measurements that had high correlation with one or more measurements: Full Girth- Hip to Waist, Full Girth- Top hip to Waist, Front Arc-Hip to Waist, Front Arc- Top hip to Waist, Back Arc- Hip to Waist, Back Arc- Top hip to Waist, Proportion- Waist to Hip/Waist to Crotch.
## Table 4.3. Bivariate correlation between initial EFA items

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<th>Front Arc - Hip to Waist</th>
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**Note:** Measurements in inches. Highlighted cells indicate measurements with high correlation.
However, high correlation values do not indicate collinearity condition solely by themselves and further investigation was required. Therefore, multiple linear regressions were conducted on the 7 identified items to find the particular measurements responsible for collinearity. In each analysis one of the 7 problematic elements was selected as the dependent variable and its corresponding highly correlated parameters were assigned as the independent variable and then the dependent variable was switched with one of the independent variables until all the cases were examined. For instance, first regression analysis was conducted with Full Girth- Hip to Waist as an independent variable and variables that had high correlation relationships with it (Full Girth- Top hip to Waist, Front Arc- Hip to Waist, Front Arc- Top hip to Waist, Back Arc- Hip to Waist, and Back Arc- Top hip to Waist) as the dependent variable. Then one of the dependent variables was assigned as independent and Full Girth- Hip to Waist was selected as dependent variables. The same process was conducted on other groups of elements with high correlations between themselves such as Front Arc and Back Arc measurements.

The Variance Inflation Factor (VIF) measuring the impact of collinearity among the variables in a regression model was examined in each test. A VIF above 2.5 indicates high correlation that confirms the existence of multicollinearity (Allison, 1999). Therefore, variables with the value above 3 were removed. Full Girth- Top hip to Waist, Front Arc- Hip to Waist, Front Arc- Top hip to Waist, Back Arc- Top hip to Waist, Back Arc- Hip to Top hip, Height- Waist to Hip, and Height proportion measurements (Waist to Hip/ Waist to Crotch, Waist to abdomen/ Waist to Crotch). Thus, out of 18 items that were used for the initial EFA analysis, 8 were removed and the rest were used for the first round of EFA analysis.
4.3.3 Factor analysis tests

After testing the collinearity conditions and removal of the highly correlated variables as explained in the previous section, the first round of EFA was performed on the 10 remaining variables listed in Table 4.4. Three components with eigen values greater than 1 were derived which explained 71.04% of the variation of the 9 variables. The results are shown in .

Table 4.4 and factors are as follows:

- Factor 1 (Girth factor) included two full girth drops (Hip to Waist, Hip to Top hip), and two back arc drops (Hip to Waist, Hip to Top hip).
- Factor 2 (Height & Length factor) was explained with one height (Waist to Crotch) and two length measurements (Side Waist to Seat, Side Waist to Hip).
- Factor 3 (Depth & Angle factor) comprised Back Seat Angle and Depth.

Table 4.4. Rotation component matrix EFA

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<tr>
<th>Rotated Component Matrixa</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Back Arc- Hip to Waist</td>
<td>.889</td>
</tr>
<tr>
<td>Full Girth- Hip to Waist</td>
<td>.858</td>
</tr>
<tr>
<td>Full Girth- Hip to Tophip</td>
<td>.818</td>
</tr>
<tr>
<td>Back Arc- Hip to Tophip</td>
<td>.663</td>
</tr>
<tr>
<td>Height- Waist to Crotch</td>
<td>.009</td>
</tr>
<tr>
<td>Length- Side Waist to Seat</td>
<td>.204</td>
</tr>
<tr>
<td>Length- Side Waist to Hip</td>
<td>.459</td>
</tr>
<tr>
<td>Back Seat Angle</td>
<td>.482</td>
</tr>
<tr>
<td>Depth</td>
<td>-.314</td>
</tr>
</tbody>
</table>
As shown in Table 4.5 the EFA analysis extracted three components with eigenvalue greater than 1.0, which represented 71.04% of the variance. Each PCs itself also had strong variation: PC1= 35.7%, PC2 = 21.1%, and PC3 = 14.1% (Table 4.5). The Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) value of the final EFA analysis was 0.603. These PC scores were saved in the dataset and used for the cluster analysis.

Table 4.5. Total variance explained from EFA

<table>
<thead>
<tr>
<th>Component</th>
<th>Eigenvalues</th>
<th>% of Variance</th>
<th>Cumulative %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.577</td>
<td>35.768</td>
<td>35.768</td>
</tr>
<tr>
<td>2</td>
<td>2.111</td>
<td>21.110</td>
<td>56.879</td>
</tr>
<tr>
<td>3</td>
<td>1.416</td>
<td>14.164</td>
<td>71.042</td>
</tr>
</tbody>
</table>

### 4.3.4 Cluster analysis

To categorize lower body shape, K-means cluster analysis was performed using the extracted factors from the EFA analysis. The Girth factor, Height and length factor, and Depth and Angle factor were used as independent variables to classify the lower body shape of 1420 men. To determine the appropriate number of clusters, 2, 3, 4, and 5 clusters were examined. It was found that the 3-cluster model explained the men’s lower body profile better than 2, 3, or 5 clusters for the reasons explained below.

The population distribution of each cluster is as follows: in 2-cluster model, the data were evenly divided into two clusters (cluster 1: n=872, 61.4%, cluster 2: n= 548, 38.5%), in the 3-cluster model 43.1% of the subjects were categorized in cluster 3 (n=613) and the remainder were categorized in cluster 1 (n= 550, 38.7%) and cluster 2 (n=257, 18.0%), in 4-cluster model, clusters
1 (n= 431, 30.3%) and cluster 2 (n= 509, 35.8%) had the largest contributions and the remaining population was unevenly shared between cluster 3 (n=159, 11.1%) and cluster 4 (n=321, 22.6%), in the 5-cluster model, the highest contribution came from cluster 1 (n=491, 34.5%) and cluster 5 (n= 452, 31.8%), the second large share belonging to cluster 2 (n=241, 16.9%) and cluster 4 (n=221, 15.5%) and finally only 1% (n=15) was assigned to cluster 3. The population distribution over the assumed number of clusters for each choice of cluster total number is presented in Table 4.6.

Table 4.6. Number of cases in 2-cluster, 3-cluster, 4-cluster, and 5-cluster model

<table>
<thead>
<tr>
<th>2-cluster Model</th>
<th>3-cluster Model</th>
<th>4-cluster Model</th>
<th>5-cluster Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>count</td>
<td>%</td>
<td>count</td>
</tr>
<tr>
<td>Cluster 1</td>
<td>872</td>
<td>61.4</td>
<td>Cluster 1</td>
</tr>
<tr>
<td>Cluster 2</td>
<td>548</td>
<td>38.5</td>
<td>Cluster 2</td>
</tr>
<tr>
<td>Cluster 3</td>
<td>613</td>
<td>43.2</td>
<td>Cluster 3</td>
</tr>
<tr>
<td>Cluster 4</td>
<td></td>
<td></td>
<td>Cluster 4</td>
</tr>
<tr>
<td>Cluster 5</td>
<td></td>
<td></td>
<td>Cluster 5</td>
</tr>
</tbody>
</table>

Examination of the ANOVA table of the 2-cluster model revealed that the Girth factor was not statistically significant, indicating that the Girth factor did not have impact on body shape classification. The 5-cluster model was also ruled out as its cluster 3 only contained 1 percent of population (n= 15), which (a) itself could restrict the ability of researcher in finding enough fit models in the pattern block development phase , (b) small cluster may not be a good a representative of a body shape category, (c) or that the small cluster belongs to a subcategory of a larger category and has clustered together due to unique features. The remaining cluster models were compared using their convergence criterion numbers. The convergence criterion
number is a value between 0 and 1 and shows the respective change in the distance between the center of clusters. A convergence criterion number that is very close to 0 indicates that the number of clusters assumed in its corresponding cluster model are optimized. In this context, the 4-cluster (cluster 1= .201, cluster 2= .129, cluster 3= .221, and cluster 4 = .607) model was excluded from further considerations as it had a larger convergence criterion number in comparison to the 3-cluster (cluster 1= .060, cluster 2= .088, and cluster 3= .031) model. Therefore, 3-cluster model was as the most appropriate model to classify men’s body shape.

To get a better understanding of each body shape category in 3-cluster model, each category was examined visually and statistically. Using Adobe Illustrator twenty body avatars from each cluster were stacked on top of each other to visually examine the ultimate silhouette of each body shape category as shown in Figure 4.2.

![Figure 4.2. Visual inspection of twenty stacked avatars from each identified body](image)

To obtain a better statistical assertion of the characteristics of each identified body shape group, the mean and standard deviation of all the three factors within each cluster were examined.
statistically. As shown in Table 4.7 and its corresponding bar graph (Figure 4.3), the Girth factor was assigned a negative value for groups A (-.53) and B (-.71), while it had a positive value for group C (.78). This indicated that group C represented a curvy silhouette while group A and B comprised mostly straight silhouette body shapes.

Regarding the Height and Length factor, a clear distinction was observed among the three groups. The Height and length factor had a large negative value for group A (-.59), a large positive value for group B (1.32), and a very close to zero value for group C (-0.24). This further confirmed that members of group B had considerable waist to hip length/height, while the waist to hip length/height was intermediate for group C and finally group A represented body shapes with the least significant waist to hip length/height. As far as Depth & Angle factor is concerned, one would need to discuss the constituent parameters in this factor separately, i.e. depth and angle, as these two variables have very different natures. With respect to back seat angle variable, group C (22.68) members have considerable larger values as compared to group A (18.19) and B (19.89). This supported our previous assertion from the Girth factor analysis, that group C had enclosed the curviest silhouette body shapes. When it comes to depth parameter, group B (12.19) represented the body shapes with highest depth, while group C (10.89) and A (10.63) had similar lower depth values. This further indicated that the large depth value of group B mostly stems from the front waist girth as compared to back waist girth. This can be interpreted as individuals belonging to group B have a body shape with a more prominent abdomen than those in group A or C. A visual inspection of Figure 4.2 confirms this finding. Additionally, group B was comprised a body shape with a lower back seat angle and girth factor than group C.
Table 4.7. Mean and SD of factors for three body shape groups with ANOVA comparison of the scores

<table>
<thead>
<tr>
<th>Body Shape Group</th>
<th>Group A (n= 550)</th>
<th>Group B (n= 257)</th>
<th>Group C (n= 613)</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S.D.</td>
<td>Mean</td>
<td>S.D.</td>
</tr>
<tr>
<td>Girth Factor</td>
<td>-.53</td>
<td>.69</td>
<td>-.71</td>
<td>1.05</td>
</tr>
<tr>
<td>Height &amp; Length Factor</td>
<td>-.59</td>
<td>.64</td>
<td>1.32</td>
<td>.93</td>
</tr>
<tr>
<td>Depth &amp; Angle Factor</td>
<td>-.49</td>
<td>.92</td>
<td>.37</td>
<td>1.05</td>
</tr>
</tbody>
</table>

Figure 4.3. Final cluster centers that shows the strength and normalized value of each factor
Table 4.8. Mean and SD of nine variables of each factor of three body shape groups

<table>
<thead>
<tr>
<th></th>
<th>Group A (n=550)</th>
<th>Group B (n=257)</th>
<th>Group C (n=613)</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S.D.</td>
<td>Mean</td>
<td>S.D.</td>
</tr>
<tr>
<td>Girth Factor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Back Arc-Hip to Waist</td>
<td>2.39</td>
<td>.67</td>
<td>2.55</td>
<td>.93</td>
</tr>
<tr>
<td>Full Girth-Hip to Waist</td>
<td>3.95</td>
<td>1.53</td>
<td>3.08</td>
<td>1.77</td>
</tr>
<tr>
<td>Full Girth-Hip to Tophip</td>
<td>1.81</td>
<td>.68</td>
<td>1.76</td>
<td>1.12</td>
</tr>
<tr>
<td>Back Arc-Hip to Tophip</td>
<td>.72</td>
<td>.41</td>
<td>.97</td>
<td>.68</td>
</tr>
<tr>
<td>Height &amp; Length</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height-Waist to Crotch</td>
<td>9.37</td>
<td>.68</td>
<td>11.43</td>
<td>.94</td>
</tr>
<tr>
<td>Length-Side Waist to Seat</td>
<td>4.69</td>
<td>.69</td>
<td>5.99</td>
<td>.99</td>
</tr>
<tr>
<td>Length-Side Waist to Hip</td>
<td>6.79</td>
<td>1.16</td>
<td>8.08</td>
<td>1.76</td>
</tr>
<tr>
<td>Depth &amp; Angle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Back Seat Angle</td>
<td>18.19</td>
<td>3.58</td>
<td>19.89</td>
<td>3.96</td>
</tr>
<tr>
<td>Depth</td>
<td>10.63</td>
<td>.96</td>
<td>12.19</td>
<td>1.11</td>
</tr>
</tbody>
</table>

Considering the statistical and visual discussion of factors over the three identified body shape groups, it was concluded that group C (curvy shape) had the curviest silhouette as it had highest girth factor and highest back seat angle compared to groups A and B. Furthermore, group A (flat-straight shape) as it holds the lowest girth factor as well as lowest back seat angle and lowest depth. Finally, group B (moderate curvy-straight) was found to be in intermediate state with regard to all factors.

4.3.5 Population distribution based on three identified body shape groups

The demographic distribution of each body shape group was analyzed based on the two age ranges (Table 4.9). In the age range of 18-25, the majority of subjects were categorized in curvy shape group (53%) and the remaining subjects were unevenly distributed in flat-straight shape.
(32.9%) and moderate curvy-straight shape (14.2%). On the other hand, in the 26-35 age group, the highest contribution came from the flat-straight shape category (47.2%) and the remainder were classified in the curvy body shape category (29%) and the moderate curvy-straight group (23.8%).

Table 4.9. Body shape group and age range crosstabulation

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Group A (Flat-Straight)</th>
<th>Group B (Moderate Curvy-Straight)</th>
<th>Group C (Curvy)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td>Count</td>
<td>Count</td>
<td>Count</td>
<td></td>
</tr>
<tr>
<td>18-25</td>
<td>276 32.9%</td>
<td>119 14.2%</td>
<td>445 53.0%</td>
<td>840   59.2%</td>
</tr>
<tr>
<td>26-35</td>
<td>274 47.2%</td>
<td>138 23.8%</td>
<td>168 29%</td>
<td>580   40.8%</td>
</tr>
<tr>
<td>Total</td>
<td>550 38.7%</td>
<td>257 18.1%</td>
<td>613 43.2%</td>
<td>1420 100%</td>
</tr>
</tbody>
</table>

Table 4.10 depicts the ethnic demographic distribution among the three identified body shape categories. Most Asian subjects were categorized in the flat-straight group (54.9%) and 31% were classified in the curvy shape and the remaining Asian subjects (14.1%) belonged to the moderate curvy-straight group. Like the Asian population, the majority of Mexican-Hispanic men were classified in the flat-straight body shape group (59.5%) and also similar to the Asian population the curvy (22.3%) and the moderate curvy-straight (18.2%) body shapes had the second and third places. As far as the non-Hispanic black demographic ethnicity is concerned, the majority of subjects were allotted to the curvy body shape (64.1%) and the remaining were distributed to the moderate curvy-straight (21.8%) and the flat-straight body shape groups (14.1%), with moderate curvy-straight group being twice populated. Non-Hispanic white subjects were mainly classified in the curvy (42.4%) and the flat-straight (38.8%) body shape.
groups and 18.2% were categorized in the moderate curvy-straight group. With respect to non-Mexican Hispanic ethnicity, the majority were categorized as either the curvy (47.2%) or the flat-straight (40.2%) shape and only 12.6% were classified in the moderate curvy-straight body type group. Other ethnicities were classified as follows: curvy (44.7%), flat-straight (37.6%), and the moderate curvy-straight (17.7%).

Table 4.10. Body shape group and ethnic group crosstabulation

<table>
<thead>
<tr>
<th>Ethnic Group</th>
<th>Count</th>
<th>%</th>
<th>Count</th>
<th>%</th>
<th>Count</th>
<th>%</th>
<th>Count</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asian</td>
<td>78</td>
<td>54.9%</td>
<td>20</td>
<td>14.1%</td>
<td>44</td>
<td>31.0%</td>
<td>142</td>
<td>10%</td>
</tr>
<tr>
<td>Mexican-Hispanic</td>
<td>88</td>
<td>59.5%</td>
<td>27</td>
<td>18.2%</td>
<td>33</td>
<td>22.3%</td>
<td>148</td>
<td>10.4%</td>
</tr>
<tr>
<td>Non-Hispanic black</td>
<td>31</td>
<td>14.1%</td>
<td>48</td>
<td>21.8%</td>
<td>141</td>
<td>64.1%</td>
<td>220</td>
<td>15.3%</td>
</tr>
<tr>
<td>Non-Hispanic white</td>
<td>249</td>
<td>38.8%</td>
<td>121</td>
<td>18.8%</td>
<td>272</td>
<td>42.4%</td>
<td>642</td>
<td>45.2%</td>
</tr>
<tr>
<td>Non-Mexican Hispanic</td>
<td>51</td>
<td>40.2%</td>
<td>16</td>
<td>12.6%</td>
<td>60</td>
<td>47.2%</td>
<td>127</td>
<td>8.9%</td>
</tr>
<tr>
<td>Other</td>
<td>53</td>
<td>37.6%</td>
<td>25</td>
<td>17.7%</td>
<td>63</td>
<td>44.7%</td>
<td>141</td>
<td>9.9%</td>
</tr>
<tr>
<td>Total</td>
<td>550</td>
<td>38.7%</td>
<td>257</td>
<td>18.1%</td>
<td>613</td>
<td>43.2%</td>
<td>1420</td>
<td>100%</td>
</tr>
</tbody>
</table>

4.4 Phase 2: Develop Basic Block Pattern for Each Body Type

4.4.1 Selecting fit models for each body shape

The fit model selection was characterized based on the three factor average values and was carried out in two steps. In the first step, the average value of all three factors (girth factor, height & length factor, and depth &angle factor) were calculated for each body shape group. Later a fit
model was selected within each body shape that had the closest factor values to the calculated averages in the previous step. Table 4.11 shows the factor characteristics of each fit model and compares it to the average factor values for each body shape. As expected, it was impossible to find a perfect fit model so that its factors precisely matched the average values, and there existed a 3-5% deviation between the factor parameters of each fit model and the calculated average values. It is noteworthy to mention that in each body shape group several fit model candidates were identified with factor values that were in the ±5% vicinity of the average. The final fit model was selected such that the factors that had larger contributions to the body shape category stayed closer to the average values.

Table 4.11. Mean of the factors of each three body shape groups and their selected fit model

<table>
<thead>
<tr>
<th>Body Shape Group</th>
<th>Group A (Flat-Straight)</th>
<th>Group B (Moderate curvy-straight)</th>
<th>Group C (Curvy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girth Factor</td>
<td>Mean: -.53, Fit model: -.47</td>
<td>Mean: -.71, Fit model: -.81</td>
<td>Mean: 0.78, Fit model: .65</td>
</tr>
<tr>
<td>Height &amp; Length Factor</td>
<td>Mean: -.59, Fit model: -.46</td>
<td>Mean: 1.32, Fit model: .89</td>
<td>Mean: -.024, Fit model: -.05</td>
</tr>
<tr>
<td>Depth &amp; Angle Factor</td>
<td>Mean: -.49, Fit model: -.44</td>
<td>Mean: .37, Fit model: .10</td>
<td>Mean: .21, Fit model: -.22</td>
</tr>
</tbody>
</table>

### 4.4.2 Pants simulation and fit analysis

The focus of this study in phase 2, was to develop pattern block for each identified body shape from phase 1. There are two stages in this phase. First, the patterns were made using Optitex 2D software for each body shape based on the body measurements of the representative fit models of each body shape category. Second, the patterns were tested virtually using Optitex 3D and corrected to fit the fit model of each body shape group.
Measurements of representative fit models of each body shape group that were needed to develop patterns were extracted from the SizeUSA spreadsheet (Table 4.12). Based on the waist measurements of the fit models, their size was also determined from ASTM D6240. The patterns were developed using the jean foundation method outlined in Armstrong (2005). The required measurements required for pattern drafting are as follows: waist circumference, hip circumference, front hip, back hip, crotch depth, and waist to ankle. The wearing ease value at the waist and hip level in Armstrong’s pattern drafting method are .75 and .5 inches.

Table 4.12. Fit models’ primary body measurements for drafting pants

<table>
<thead>
<tr>
<th>Body Shape Group</th>
<th>Group A (Flat-Straight)</th>
<th>Group B (Moderate Curvy-Straight)</th>
<th>Group C (Curvy)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fit Model 1</td>
<td>Fit Model 2</td>
<td>Fit Model 3</td>
</tr>
<tr>
<td>Size In ASTM</td>
<td>Size 39</td>
<td>Size 39</td>
<td>Size 37</td>
</tr>
<tr>
<td>Height</td>
<td>70</td>
<td>70.5</td>
<td>69.5</td>
</tr>
<tr>
<td>Waist to ankle</td>
<td>40.43</td>
<td>42.5</td>
<td>40.7</td>
</tr>
<tr>
<td>Crotch depth</td>
<td>9.53</td>
<td>10.44</td>
<td>10.29</td>
</tr>
<tr>
<td>Waist girth</td>
<td><strong>33.1</strong></td>
<td><strong>33.01</strong></td>
<td><strong>31.57</strong></td>
</tr>
<tr>
<td>Front waist</td>
<td>16.05</td>
<td>16</td>
<td>15.28</td>
</tr>
<tr>
<td>Back waist</td>
<td>17.05</td>
<td>17.01</td>
<td>16.29</td>
</tr>
<tr>
<td>Hip girth</td>
<td>36.78</td>
<td>34.43</td>
<td>36.93</td>
</tr>
<tr>
<td>Front hip</td>
<td>17.63</td>
<td>15.33</td>
<td>17.06</td>
</tr>
<tr>
<td>Back hip</td>
<td>19.15</td>
<td>19.1</td>
<td>19.87</td>
</tr>
</tbody>
</table>

Representative fit model of group 1 and group 2 have the same waist (group 1= 33.1, group 2=33.01) and height (group 1=70, group 2= 70.5) measurements but group 2 has longer crotch depth as the average value of the height factor of group 2 (-0.46) is higher than the average value of the height factor of group 1 (.89), which indicates that two individuals with the same body measurements may not necessarily have the same body shape, as in principle the
distribution of the fat is different. For instance, the Moderate Curvy-Straight body shape have more fat in the front when compared to the Flat-Straight body shape group. This indicates that each of them would need a different shaped pattern to accommodate for exclusive characteristics of their body shapes.

Given that the 3D-body scan cameras cannot capture crotch areas precisely, extracting crotch height from 3D-scan results has significant error margins and crotch height measurements are most likely overestimated. Pilot simulations revealed that subtracting 1-1.5 inches from waist height measurement of the SizeUSA would resolve this problem.

After completing the block pattern drafts for each body shape group, the represented fit model chosen for each group was uploaded into the Optitex 3D software for the virtual simulation of pants. The 3D avatars were imported in scale 1 and in units of millimeter. Prior to the virtual simulation process, several preset steps were completed to achieve a more realistic outcome. The fabric type, Denim-Woven (100% cotton), and the stitch type, lock-stitch, were fed into the software. Furthermore, the 3D shape and location of each pattern piece, with respect to the avatar were defined. Proper adjustment of all these presets are crucial as they have a significant impact on the simulation outcome. When adjusting the location of pattern pieces around the avatar one needs to align the pieces for proper virtual sewing. This includes making sure the garment pieces are sewn together on the proper adjoining seam line while avoiding the pattern pieces colliding with the avatar.

Once the simulation process was completed, the tension map tool was used to evaluate and analyze the fit of the virtual pants both visually and numerically. The tension (gf/cm), stretch (%) and collision (dyne/ cm²) parameters were used for quantitative evaluation of the fit in the simulated garment. Tension (fg/cm) and stretch (%) indicate the same phenomenon, the amount
of material distortion away from its default shape, in different formats. The collision parameter represents the effective distance between the virtual fabric and the virtual model by the amount of pressure applied from the fabric on the model. It is noteworthy that tension and stretch are evaluated in three ways: weft direction (X), warp direction (Y) and total (XY).

After going through all the presets and carrying out the simulation itself the tension, stretch, and collision parameters; and the virtual pants were sewn virtually for each body shape group. It is noteworthy to mention that when denim (100% cotton) was chosen as the virtual fabric for the fit model of group three, the pants did not sew completely on the body as the fit model had a muscular thigh, which was not foreseen in the initial pattern (Figure 4.4). Therefore, the inseam and the outseam of both front and back were moved towards outside by 0.25 inches to accommodate the thigh of the model.

As the value of tension, stretch and collision changed with each simulation by repositioning the piece, the pants were simulated five times and the value of these parameters was recorded each time, which is summarized in Table 4.13.
Table 4.13. Values of tension, stretch, and collision of simulated pants for all body type groups in five simulations

<table>
<thead>
<tr>
<th>Body Type</th>
<th>Tension</th>
<th>Stretch</th>
<th>Collision</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>XY</td>
<td>X</td>
<td>Y</td>
</tr>
<tr>
<td>Flat-Straight</td>
<td>368.50</td>
<td>91.70</td>
<td>345.51</td>
</tr>
<tr>
<td></td>
<td>369.16</td>
<td>98.92</td>
<td>343.98</td>
</tr>
<tr>
<td></td>
<td>363.28</td>
<td>90.86</td>
<td>341.29</td>
</tr>
<tr>
<td></td>
<td>365.97</td>
<td>97.90</td>
<td>341.02</td>
</tr>
<tr>
<td></td>
<td>349.90</td>
<td>86.34</td>
<td>328.91</td>
</tr>
<tr>
<td>Moderate curvy-straight</td>
<td>112.55</td>
<td>28.27</td>
<td>105.76</td>
</tr>
<tr>
<td></td>
<td>134.81</td>
<td>34.85</td>
<td>125.88</td>
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<tr>
<td></td>
<td>135.07</td>
<td>30.67</td>
<td>128.23</td>
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<td></td>
<td>117.71</td>
<td>33.5</td>
<td>108.55</td>
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<tr>
<td></td>
<td>118.59</td>
<td>33.37</td>
<td>109.09</td>
</tr>
<tr>
<td>Curvy</td>
<td>364.93</td>
<td>83.72</td>
<td>347.92</td>
</tr>
<tr>
<td></td>
<td>356.56</td>
<td>89.19</td>
<td>335.19</td>
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<td></td>
<td>359.61</td>
<td>82.89</td>
<td>340.82</td>
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<td></td>
<td>355.04</td>
<td>86.7</td>
<td>336.22</td>
</tr>
<tr>
<td></td>
<td>334.89</td>
<td>77.62</td>
<td>318.65</td>
</tr>
</tbody>
</table>

Results of the tension, stretch, and collision values derived from the five simulations were then averaged for the fit analysis (Table 4.14).

Table 4.14. Average of tension, stretch, and collision in five simulations

<table>
<thead>
<tr>
<th>Body Type</th>
<th>Tension</th>
<th>Stretch</th>
<th>Collision</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>XY</td>
<td>X</td>
<td>Y</td>
</tr>
<tr>
<td>Flat-Straight</td>
<td>363.36</td>
<td>93.14</td>
<td>340.14</td>
</tr>
<tr>
<td>Moderate curvy-straight</td>
<td>123.75</td>
<td>32.13</td>
<td>115.50</td>
</tr>
<tr>
<td>Curvy</td>
<td>354.20</td>
<td>84.02</td>
<td>335.76</td>
</tr>
</tbody>
</table>
Examination of the drape parameters revealed that each body shape group experienced different fitting issues. In Figure 4.5, virtual pants were shown in spring modes and tension XY over all the three body types of actual 3D avatar. Even though the fit model of group 1 and group 2 were both in a same size range (size 39), their fitting issues were not similar, as their body shapes were different. To obtain more insight, the springs and tension map modes were also examined. The tension map mode of Optitex 3D uses color to define areas of tension. The color ranges from blue through green and yellow to red. Blue indicates the minimum tension and red indicates the maximum value of tension. However, the red and blue always appear. It is noteworthy to mention that a red color does not necessarily indicate the cloth is very tense (Optitex Help Center, n.d). It should be noted that the mere reeducation of the tension, stretch, and collision parameters, does not always indicate better fit and sometimes resolving fitting issues is accompanied by enhancement in fabric parameters values. To elaborate, if the initial simulated pants are very tight, and thus, the fabric is under considerable tension in weft or warp direction, improving fit would result in lower tension values. On the other hand, if the initial simulated pants is very loose improving fit means slightly higher tension and collision values. The fitting problems of each group will be discussed separately.
4.4.3 Fit analysis and pattern alteration of the Flat-Straight body shape group

The first step to develop a basic block pattern for each body shape is to identify the fitting issues that each group may experience. Then decide the locations that need the alterations to achieve the desire fit. Therefore, the fit of the pants for each body shape was analyzed from different perspectives using: the springs, display unique color, stretch, collision, and the add circumference tools. As the values for tension and stretch indicate the same phenomenon, but in different formats, the researcher decided to use only the stretch value. The Stretch X color map of the virtual pants before and after refining patterns were used as the stretch in virtual fabric is mostly active in the weft direction (Sayem, 2017).
Close examination of the virtual pants (Figure 4.7, Figure 4.8) for the Flat-Straight body shape group revealed that the representative fit model of this group has fitting issues at thigh, crotch level, below back seat, length, and the front and back waist line. The waist and hip girth and intended ease were examined using “add circumference measure” tool.

Figure 4.6. Pattern of the Flat-Straight group before alteration

Figure 4.7. Front, back, and side views of the Flat-Straight body shape group with virtual pants
Examination of the color band on the fit models revealed that the body is not exactly symmetrical as the range of the color found to be different on each side of the body (Figure 4.9). as well as the wrinkles. This was confirmed by an examination of the raw measurement data extracted from the 3D body scan. When choosing the anthropometric measurements to use in apparel pattern drafting it is standard procedure to take the measurement from the larger side of the individual. Therefore, for the purpose of refining the pattern, the side that has the largest circumference was considered for fitting evaluation.

Figure 4.8. Three views of the Flat-Straight body shape group with virtual pants in springs
After conducting fit analysis and identifying fit issues, alteration of the ill-fitted pattern was started. After each alteration, the 2D patterns were updated for 3D simulation. The advantage of using virtual prototyping and virtual try-on is that the fitting sessions are not limited, and the researcher can conduct as many fitting simulations as needed. The alterations began with the waist line and after each round that contained two or three modifications, screen shots were taken and areas that were altered were described in captions. In the following fitting analysis, the Stretch X drape parameter was included as previous researchers have discovered that “the stretch in virtual fabric is mostly active in weft direction” (Sayem, 2017, p.181).

The ease amount at the waist and hip area were examined using the “add circumference measure” tool (Figure 4.10). Although the ease amount at the hip and the waist of prototype pants were correct but fit problems were found across the waist and hip area. Therefore, the intended ease at the waist was removed from the pattern (Figure 4.11). This confirmed McKinney et al. (2012) that “ease amount needed at the waist for good fit vary in relationship to location of buttocks prominence. Low Flat Back and Low Sway Back buttocks shapes had negative ease amounts at the waist circumference” (p. 161).
Diagonal wrinkles or drag lines radiated from the front crotch inseam, indicated seat and thigh width issues (Figure 4.11a). The crotch extension was prolonged 0.25 inch to release the front inseam. Then front inseam crotch was extended 0.75 inch (Figure 4.11b)

Figure 4.10. Ease amount at waist (blue) and hip (red) level using “add circumference measure”

Figure 4.11. Front crotch inseam extended 0.25 inch. Front crotch inseam was extended 0.75 inch and scooped in 0.25 inch, 0.5 inch was taken from CF at waistline to remove gap at CF.
The final front and back look of altered pants on the 3D avatar with the Stretch X mapping are shown in Figure 4.13a and Figure 4.14b.

Figure 4.12: (a) The tight thigh resulted in dragging back inseam crotch and the V-shape waistline; (b) front and back crotch extended 0.75 inch, side seam at hip level curved out 0.25

Figure 4.13. The front waist was moved to the midway of the front waist line, two 0.5 inch darts were taken at front inseam crotch at high hip level and crotch level
Figure 4.14. Three darts were taken at CB inseam crotch, 0.5 inch at crotch level, 0.5 inch at high hip level, 0.25 inch above high hip. The back dart moved to the midway of the back waistline.

One should point out that some of the wrinkles on the final virtual pants, such as the horizontal wrinkle at back seat, were caused by the wrinkles of the model’s underwear when scanned (see Figure 4.15). Also, due to the intrinsic properties of 100% cotton fabric, such as thickness and stiffness, wrinkles have more visibility than thin or stretch fabrics.

Figure 4.15. Wrinkles of the model’s underwear are transferred to the virtual pants.

The fitting of the virtual pants for the Flat-Straight body shape group, before and after alteration are shown in Figure 4.16.
The final shape-driven block pattern for the Flat-Straight body shape group was superimposed over the original block draft to compare changes that took place during fitting (see Figure 4.17).

![Figure 4.16. Comparison of (a) initial virtual pants with common fit problems of the Flat-Straight body shape group and (b) corrected virtual fitted pants with proper fit from crotch to hip area](image)

![Figure 4.17. Comparison of the first block (in black) and the final shape-driven block pattern (in red) for the Flat-Straight body shape group](image)

The maximum values of tension, collision, and minimum and maximum values of stretch for the initial pattern and shape-driven pattern are listed in Table 4.15. Generally, the drape
parameters values for the virtual pants with the shape-driven pattern decreased notably. For the selected virtual fabric of this simulation, the maximum total tension for the initial virtual pants was 363.36 and which decreased significantly in the virtual pants simulated with the shape-driven pattern.

Table 4.15. Average of tension, stretch, and collision in five simulations for the Flat-Straight body shape group before and after fitting

<table>
<thead>
<tr>
<th></th>
<th>Tension</th>
<th>Stretch</th>
<th>Collison</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>XY</td>
<td>X</td>
<td>Y</td>
</tr>
<tr>
<td>Initial pattern</td>
<td>363.36</td>
<td>93.14</td>
<td>340.14</td>
</tr>
<tr>
<td>Shape – driven pattern</td>
<td>203.16</td>
<td>67.80</td>
<td>182.79</td>
</tr>
</tbody>
</table>

4.4.4 Fit analysis of the moderate Curvy-Straight body shape group

The personal measurement of the representative fit model of second group was used to draft a pants pattern. After drafting a pattern for the selected fit model and uploading the 3D avatar of the model and simulating the pants, the researcher faced two issues. The wrinkles and color map were not identical on both sides of the body, which indicated that the body of this fit model was asymmetrical (Figure 4.18). After careful examination of the fit model’s body measurements, it was found that the asymmetrical color map originated from the model shape itself and not the simulation process.
Another issue, which was more pronounced, was caused by the model’s underwear while scanned. As it was explained before, all the wrinkles and folds of a model’s underwear will be transferred to the virtual garment in virtual simulation (Figure 4.19).

Due to the discussed issues, the fitting of the pattern was not accurate as the fitting were acceptable on one side and not acceptable on the other side. As it was shown in Figure 4.20, the fitting of the pants looks better on the left compared to the right side.
Therefore, the researcher decided to select another fit model to refine and develop a more accurate shape-driven block pattern for this group. Another fit model that the values of the factors were close to the average value of its group was selected as a representative of this group. Body measurements of the selected fit model were extracted from the SizeUSA spreadsheet (listed in Table 4.12) to draft the pants pattern (Figure 4.21).
The fit model of group 1 and group 2 have the same height (group 1=70, group 2=70.5), waist (group 1 = 33.1, group2 = 33.01), and approximately the same hip measurements (group1= 36.78, group 2= 34.43), and both fit in size 39 based on the ASTM measurements. However, they experienced different fitting issues, which indicated that two individuals with the same body measurements could certainly face different fitting issues as their body were shapes are not the same.

In the Moderate Curvy-Straight body shape group, the fat distribution is more in the front part of the body when compared to the Flat-Straight body shape group. Close examination of the virtual pants (Figure 4.22, Figure 4.23) for the Moderate Curvy-Straight body shape group revealed that the representative fit model of this group has fitting issues at crotch level, length, and the front and back waist line, same as the fit model of group 1.
To remove the gap and the wrinkles radiating from the center front inseam, the crotch extension were prolonged 0.6 inch and the center front point at waist moved 0.25 inch and 0.4 toward the inside (Figure 4.24).

(a) Before front, Stretch X (-0.79 – 0.62)  (b) After front, Stretch X (-0.57 – 0.45)

Figure 4.24. Crotch extension prolonged 0.6 inch and the center front waistline point moved 0.25 inch up and 0.4 inch in.

The fitting issues at the front inseam were not completely solved by extending the crotch extension and the front inseam (see Figure 4.25a). The Moderate Curvy-Straight body shape has
more fat in the front compared to the other groups. Therefore, 0.5 inch was added to the length of the front dart and one 0.3 inch dart was taken from the front inseam and 0.2 inch dart was taken from side seam at high hip level. Then the length of the side seams was trued.

![Figure 4.25. The front dart extended for 0.5 inch, 0.3 inch dart was taken from the front inseam and 0.2 inch dart was taken from side seam at high hip level](image)

To fix the fitting problems in the back, crotch extension was lengthen 0.25 inch, then 0.25 inch dart was taken from the center back crotch inseam (Figure 4.26).

![Figure 4.26. Back crotch extension prolonged 0.25 inch, 0.25 inch dart taken from back crotch inseam](image)

The fitting of the virtual pants for the Flat-Straight body shape group, before and after alteration are shown in Figure 4.27.
Figure 4.27. Comparison of (a) initial virtual pants with common fit problems of the Moderate Curvy-Straight body shape group and (b) corrected virtual fitted pants with proper fit from crotch to hip area.

The final shape-driven block pattern for the Flat-Straight body shape group was superimposed over the original block draft to compare changes that took place during fitting (see Figure 4.28).

Figure 4.28. Comparison of the first block (in black) and the final shape-driven block pattern (in red) for the Moderate Curvy-Straight body shape group.
The maximum values of tension, collision, and minimum and maximum values of stretch for the initial pattern and shape-driven pattern are listed in Table 4.16.

Table 4.16. Average of tension, stretch, and collision in five simulations for the Flat-Straight body shape group before and after fitting

<table>
<thead>
<tr>
<th></th>
<th>Tension (XY, X, Y)</th>
<th>Stretch (XY, X, Y)</th>
<th>Collision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial pattern</td>
<td>123.75 32.13 115.50</td>
<td>-1.59 1.55 -0.76 0.59 -0.83 1.99</td>
<td>24510.92</td>
</tr>
<tr>
<td>Shape – driven pattern</td>
<td>126.10 27.21 120.80</td>
<td>-1.54 1.60 -0.38 0.32 -1.23 2.05</td>
<td>19648.88</td>
</tr>
</tbody>
</table>

### 4.4.5 Fit analysis of the Curvy body shape group

The pants pattern was developed based on the body measurement of the representative fit model of the Curvy body shape group. The pattern was drafted in Optitex 2D (see Figure 4.29).

Figure 4.29. Initial drafted pattern of the Curvy group before alteration
The pattern was then virtually sewn and simulated on the 3D avatar for fit assessment. The overall fit of the virtual pants was examined in with different fitting assessment tools. The fit was first examined visually (see Figure 4.30) to find the ill-fitted area for pattern alteration.

![Figure 4.30. Front, back, and side views of the Curvy body shape group with virtual pants](image)

The pants were then evaluated for fit using the springs mode (see Figure 4.31).

![Figure 4.31. Three views of the Curvy body shape group with virtual pants in springs mode](image)
Finally, the stretch map was used to further observe the fit (see Figure 4.32).

![Stretch Map](image)

**Figure 4.32.** Stretch map on the simulated pants from the Curvy body shape

Diagonal drag lines radiated from the center front inseam and a V-shaped waist line was visible in all three modes, indicating that there was a problem with seat width. The formula for crotch extension of the jeans foundation outlined in Armstrong (2005) is based on a percentage of hip measurement regardless of body shape. However, changes in the configuration of the body required changes in crotch extension. Therefore, to solve the fitting issue at center front and back crotch inseam, 0.5 inch (Figure 4.33) and 0.75 inch (Figure 4.34) were added to the front and back crotch extension.

Therefore, to solve the fitting issue at center front and the back crotch inseam, 0.5 inch (Figure 4.33) and 0.75 inch (Figure 4.34) were added to the front and back crotch extension.

![Crotch Extension](image)

(a) Front before, Stretch X (-0.96 – 1.00)  
(b) Front after, stretch X (-.65 -.64)

**Figure 4.33.** Front crotch extension extended 0.5 inch
Examination the side seam of the virtual pants revealed that the side seam is not straight. It is noteworthy to mention that examination of the side seam is challenging on the actual 3D avatar compare to the default avatars of Optitex, as it is not possible to lift his hand to check the fitting of the pants from the side. However, because of the missing data below the elbow and around the wrist, the researcher was able to check the fitting of the pants from the side view through the hole created as a result of missing data (see Figure 4.35).

Figure 4.35. Examination the side seam through the hole created as a result of missing data below the elbow. The side seam was moved toward the back by 0.5 inch.

The fitting of the virtual pants for the Curvy body shape group, before and after alteration are shown in Figure 4.36.
Figure 4.36. Comparison of (a) initial virtual pants with common fit problems of the Curvy body shape group and (b) corrected virtual fitted pants with proper fit from crotch to hip area

The maximum values of tension, collision, and minimum and maximum values of stretch for the initial pattern and shape-driven pattern are listed in Table 4.17. Generally, the drape
parameters values for the virtual pants with shape-driven pattern decreased notably. For the selected virtual fabric of this simulation, the maximum total tension for initial virtual pants was 354.20 which decreased significantly in the virtual pants simulated with shape-driven pattern.

Table 4.17. Average of tension, stretch, and collision in five simulations for the Curvy body shape group before and after fitting

<table>
<thead>
<tr>
<th></th>
<th>Tension</th>
<th>Stretch</th>
<th>Collison</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>XY</td>
<td>X</td>
<td>Y</td>
</tr>
<tr>
<td>Initial pattern</td>
<td>354.20</td>
<td>84.02</td>
<td>335.76</td>
</tr>
<tr>
<td>Shape – driven pattern</td>
<td>175.59</td>
<td>53.62</td>
<td>163.40</td>
</tr>
</tbody>
</table>

Overall, in this phase three fit models were selected for each body shape group based on the average value of the three factors that were used to classify the body shapes. Furthermore, the pants patterns were exclusively drafted for each fit model based on their individuals body measurements. Then multiple virtual fits were conducted on the drafted patterns to develop the optimized block pattern for each group. One can rule out the need for additional fit models as the current fit models were selected such that their measurements represented the average value of all the three factors used to classify the body shapes.

4.5 Comparison of the shape-driven block patterns

In Figure 4.38, the three final shape-driven block patterns were superimposed for comparison. As the fit models had different height (fit model 1=70, fit model 2=70.5, fit model 3=69.5) the patterns were aligned and placed over each other based on their hip level. The body measurements of the fit models, which were used to draft the initial patterns are listed in
Table 4.18. Also, the average value of the variables that were used for body shape categorization with the values of the fit models are summarized in Table 4.19.

Figure 4.38. The final three shape-driven block patterns

Group A- Flat-Straight

Group B- Moderate Curvy-Straight

Group C- curvy
Table 4.18. Fit models’ body measurements

<table>
<thead>
<tr>
<th>Body Shape Group</th>
<th>Group A (Flat-Straight)</th>
<th>Group B (Moderate curvy-straight)</th>
<th>Group C (Curvy)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fit Model 1 (#0500149)</td>
<td>Fit Model 2 (#2739)</td>
<td>Fit Model 3 (#2659)</td>
</tr>
<tr>
<td>Height</td>
<td>70</td>
<td>70.5</td>
<td>69.5</td>
</tr>
<tr>
<td>Weight</td>
<td>160</td>
<td>140</td>
<td>151</td>
</tr>
<tr>
<td>Waist to ankle</td>
<td>40.43</td>
<td>42.5</td>
<td>40.7</td>
</tr>
<tr>
<td>Crotch depth</td>
<td>9.53</td>
<td>10.44</td>
<td>10.29</td>
</tr>
<tr>
<td>Waist girth</td>
<td><strong>33.1</strong></td>
<td><strong>33.01</strong></td>
<td><strong>31.57</strong></td>
</tr>
<tr>
<td>Hip girth</td>
<td>36.78</td>
<td>34.43</td>
<td>36.93</td>
</tr>
</tbody>
</table>

Table 4.19. Average factor value of each body shape groups and the selected fit models

<table>
<thead>
<tr>
<th>Body Shape Group</th>
<th>Group A (Flat-Straight)</th>
<th>Group B (Moderate curvy-straight)</th>
<th>Group C (Curvy)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Fit model</td>
<td>Mean</td>
</tr>
<tr>
<td>Girth Factor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Back Arc- Hip to Waist</td>
<td>2.39</td>
<td>2.1</td>
<td>2.55</td>
</tr>
<tr>
<td>Full Girth- Hip to Waist</td>
<td>3.95</td>
<td>3.68</td>
<td>3.08</td>
</tr>
<tr>
<td>Full Girth- Hip to Tophip</td>
<td>1.81</td>
<td>1.75</td>
<td>1.76</td>
</tr>
<tr>
<td>Back Arc- Hip to Tophip</td>
<td>0.72</td>
<td>0.92</td>
<td>0.97</td>
</tr>
<tr>
<td>Height &amp; Length Factor</td>
<td></td>
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</tr>
<tr>
<td>Height- Waist to Crotch</td>
<td>9.37</td>
<td>9.44</td>
<td>11.43</td>
</tr>
<tr>
<td>Length- Side Waist to Seat</td>
<td>4.69</td>
<td>4.51</td>
<td>5.99</td>
</tr>
<tr>
<td>Length- Side Waist to Hip</td>
<td>6.79</td>
<td>8.54</td>
<td>8.08</td>
</tr>
<tr>
<td>Depth &amp; Angle Factor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Back Seat Angle</td>
<td>18.19</td>
<td>17.26</td>
<td>19.89</td>
</tr>
<tr>
<td>Depth</td>
<td>10.63</td>
<td>9.8</td>
<td>12.19</td>
</tr>
</tbody>
</table>

The most noticeable difference between the patterns was the variation of waist to crotch height among different patterns. From the fit model measurements point of view, the height of the waist to crotch measurement of group B (the Moderate Curvy-Straight) was the highest (10.43), while the fit model of group A (the Flat-Straight) had the shortest waist to crotch height (9.44), and the fit model of group C (the Curvy) had the medium height (10.23). The same
hierarchy is also reflected in the cluster mean values of waist to crotch measurement with the Moderate Curvy-Straight having the highest length followed by the Curvy and Flat-Straight groups with medium and shortest lengths, respectively. This is consistent with the appearance of the shape-driven patterns front view shown in Figure 4.38. As the Flat-Straight pattern (green) clearly shows the shortest length followed by the Curvy (blue) and the Moderate Curvy-Straight (red) groups’ patterns representing the medium and largest lengths. This grading is also repeated for the back piece of the shape-driven patterns, except the Curvy (blue) and the Moderate Curvy-Straight (red) patterns showing almost the same lengths. The unprecedented equal waist to crotch lengths of Curvy (blue) and the Moderate Curvy-Straight (red) patterns in the back view can be understood when considering that the Curvy group has the most prominent buttocks compared to the other two groups which itself requires longer length accommodated in the pattern to address this feature.

Another difference among the patterns is depicted in the back crotch inseam slope which was influenced by the back seat angle measurement. As far as the back seat angle measurements of the fit models are concerned, the back seat angle measurement of group C (the Curvy) was the highest (21.60°), while the fit model of group A (the Flat-Straight) had the smallest (17.26°) and the fit model of group B (Moderate Curvy-Straight) had the medium back seat angle (19.41°). This is consistent with the slope of back crotch inseam shown in the figure with Curvy group (blue) showing the smallest slope (largest angle) and the Flat-Straight (green) group representing the largest slope (smallest angle) and the Moderate Curvy-Straight group (red) showing the medium slope value.

The third distinguishable parameter among the three shape-driven patterns was the silhouette of the side seam. The Curvy group (blue) shows the curviest side seam, while the Flat-
Straight group (green) has the straightest side seam and the Moderate Curvy-Straight group (red) side seam’ shape falling in between the other two groups.

Another variance among the three Shape-driven block patterns was the center front inseam slope, which was influenced by the depth variable. The Fit model of group B (Moderate Curvy-Straight) had the highest depth value of 10.67 while the fit model of group A (the Flat-Straight) had the lowest value of depth equaling 9.8 and finally group C (the Curvy) had the medium depth value of 10.54. This is consistent with the grading of center front inseam slope among the three patterns with the Moderate Curvy-Straight group (red) having the largest slope followed by the Curvy group (blue) and the Flat-Straight group (green) that depict the medium and lowest values of center front inseam slope. Another factor that can also contribute to the hierarchy observed in the value of center front inseam slope is the uneven fat distribution around the waist and hip areas. The Moderate Curvy-Straight group has more fat accumulation in the front and thus represents the largest value of center front inseam slope to accommodate the fat in the front. To elaborate more, the waist measurement (group A=33.1, group B=33.01) and almost the hip measurements (group A=36.78, group B=34.43) of the fit model group A and group B were the same but the silhouette of the shape-driven block pattern were different. This indicates that although they have the same body measurements, and both fit in Size 39 based on ASTM measurements but the fat distribution around the waist and hip was different, which categorized them in different body shape group. Also, their fit issues and fit needs are different from each other, which can be seen in the different shape of their final shape-driven block pattern.

Analyzing the difference in crotch extension among different body shape groups was difficult as the length of the crotch extension is allied to other variables such as the max thigh girth, hip girth and depth. For instance, the crotch extension of the Flat-Straight group (red) was
almost equal to the crotch extension of the Moderate Curvy-Straight group (green) as the fit model of the Flat-Straight group had a muscular thigh and the crotch was extended to release the pants leg around the thigh.

4.6 Phase 3: Validation of Shape-driven Block

The purpose of phase 3 was to validate the developed block patterns by comparing the appearance and fit of pants using the shape-driven block pattern made for a specific body shape category on three fit testers from each body shape. Also, a simulated pants developed based on current ASTM measurements on a fit tester from the same body shape category was compared with virtual pants of the three fit testers. Totally nine fit models (3 body shape group × 3 fit testers) were chosen and twelve pants (3 body shape group × 4 virtual pants) were simulated for fit validation of the developed shape-driven block (Table 4.20). Therefore, four simulations were conducted:

1. Two simulations on the fit tester of the same body shape group: one with shape-driven block pattern and one with the pattern developed based on ASTM body measurements.
2. Two simulations using the shape-driven block pattern on two fit testers from different body shape group, other than the shape-driven block pattern, with the same waist measurements.

Due to lack of accurate grading methodology, fit testers for each body shape were selected as follows to prevent using grading practice. The primary body measurements for selecting fit testers was waist circumference as the size of men’s jeans in the apparel industry is categorized based on the waist measurement. Therefore, in each body shape group several fit tester candidates were identified with waist girth values that were in the ±0.5inch vicinity of the fit
models’ waist measurement. It is noteworthy to mention that no alterations or modifications were performed after the simulations and the results presented here are the direct outcome of virtual simulation on the fit testers except for adjustment of the length. It is expected that with the shape-driven block patterns less fitting issues would occur and the desired fit would be achieved in at most 2 fitting sessions.

Table 4.20. Fit testers and pants simulations

<table>
<thead>
<tr>
<th>Body Shape Groups</th>
<th>1st simulation</th>
<th>2nd simulation</th>
<th>3rd simulation</th>
<th>4th simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat-Straight</td>
<td>Pants simulated with the shape-driven block pattern of the Flat-Straight body shape group on a fit tester from the same body shape group</td>
<td>Pants simulated with the single block pattern (ASTM) on a fit tester from the same body shape group</td>
<td>Pants simulated with the shape-driven block pattern of the Flat-Straight body shape group on a fit tester from the Moderate Curvy-Straight body shape group</td>
<td>Pants simulated with the shape-driven block pattern of the Flat-Straight body shape group on a fit tester from the Curvy body shape group</td>
</tr>
<tr>
<td>Moderate Curvy-Straight</td>
<td>Pants simulated with the shape-driven block pattern of the Moderate Curvy-Straight body shape group on a fit tester from the same body shape group</td>
<td>Pants simulated with the single block pattern (ASTM) on a fit tester from the same body shape group</td>
<td>Pants simulated with the shape-driven block pattern of the Moderate Curvy-Straight body shape group on a fit tester from the Flat-Straight body shape group</td>
<td>Pants simulated with the shape-driven block pattern of the Flat-Straight body shape group on a fit tester from the Curvy body shape group</td>
</tr>
<tr>
<td>Curvy</td>
<td>Pants simulated with the shape-driven block pattern of the Curvy body shape group on a fit tester from the same body shape group</td>
<td>Pants simulated with the single block pattern (ASTM) on a fit tester from the same body shape group</td>
<td>Pants simulated with the shape-driven block pattern of the Curvy body shape group on a fit tester from the Flat-Straight body shape group</td>
<td>Pants simulated with the shape-driven block pattern of the Curvy body shape group on a fit tester from the Moderate Curvy-Straight body shape group</td>
</tr>
</tbody>
</table>
Three fit testers were selected randomly from the potential subjects to compare the fit of the pants made from shape-driven block pattern with a single block pattern that was developed based on ASTM measurements. The fit model of the group 1 and 2 were found to be size 39 and the fit model of group 3 was found to be size 37. Therefore, two patterns were developed in regular size 39 and size 37, the measurements are presented in Table 4.21.

<table>
<thead>
<tr>
<th></th>
<th>Size 37</th>
<th>Size 39</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waist to ankle</td>
<td>42.63</td>
<td>42.63</td>
</tr>
<tr>
<td>Crotch depth</td>
<td>10.63</td>
<td>10.63</td>
</tr>
<tr>
<td>Waist girth</td>
<td>31.5</td>
<td>33.5</td>
</tr>
<tr>
<td>Hip girth</td>
<td>36.5</td>
<td>38.5</td>
</tr>
</tbody>
</table>

Since a significant difference between the length and hip measurements of either the shape-driven or single block pattern with the fit testers could have negative effect on the simulation process, these two measurements were adjusted if needed. To elaborate, when the pants are too long, the virtual pants would collide with the feet of the 3D avatar and prevents proper simulation. The same effect would occur if the hip measurement is very off as shown in Figure 4.4.

4.6.1 Comparison of fit of the pants from shape-driven block pattern and a single block pattern for the Flat-Straight body shape group

Three fit testers from each body shape group, with approximately the same body measurements as of the measurements of the fit model that was used to develop the shape-driven block pattern for the Flat-Straight group, were selected for validation phase. The average value
of each factor for this body shape category as well as the factor values of the three fit testers were listed in Table 4.22. Also, the body measurements of the selected fit testers were summarized in Table 4.23.

Table 4.22. Average factor values of the Flat-Straight group and the factor values of the three selected fit testers

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Flat-Straight Body Shape Fit Testers</th>
<th>Fit Tester 1 from Flat-Straight (#304)</th>
<th>Fit Tester 2 from Moderate Curvy-Straight (#739)</th>
<th>Fit Tester 3 from Curvy (#918)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girth Factor</td>
<td>-0.53</td>
<td>-0.46</td>
<td>-0.82</td>
<td>0.37</td>
<td></td>
</tr>
<tr>
<td>Height &amp; Length Factor</td>
<td>-0.59</td>
<td>-0.33</td>
<td>0.87</td>
<td>-0.36</td>
<td></td>
</tr>
<tr>
<td>Depth &amp; Angle Factor</td>
<td>-0.49</td>
<td>-1.75</td>
<td>0.11</td>
<td>0.40</td>
<td></td>
</tr>
</tbody>
</table>

Furthermore, Table 4.23 includes the primary body measurements of the three fit testers and the fit representative of this body shape category. As the size of fit model of the Flat-Straight body shape group was 39, all the fit testers were also selected from size 39. Also, the body measurements of size 39 of the ASTM were used to draft a pattern using Armstrong’s instructions. Comparison of body measurements in Table 4.23 indicated that individuals’ sizes and body shapes are not related, which indicates that individuals within the same size category do not have necessarily the same body shape. Examination of ASTM measurements showed that the body shape factor was not considered in developing sizing system, and size charts were developed based on regular body shape that do not consider any information regarding consumer’s body shape (ASTM, 2012). Therefore, knowledge of the body shape is necessary to address and solve fit problems and produce well-fitting clothing that meets wants and needs of consumers.
Table 4.23. Primary body measurements for the three selected fit testers and the fit model from the Flat-Straight group

<table>
<thead>
<tr>
<th>Height</th>
<th>Fit Model</th>
<th>Fit tester 1 from Flat-Straight (#304)</th>
<th>Fit tester 2 from Moderate Curvy-Straight (#739)</th>
<th>Fit tester 3 from Curvy (#918)</th>
<th>ASTM Size 39</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>70</td>
<td>69</td>
<td>70.5</td>
<td>66</td>
<td>70</td>
</tr>
<tr>
<td>Waist to ankle</td>
<td>40.43</td>
<td>40.86</td>
<td>42.5</td>
<td>38.34</td>
<td>42.63</td>
</tr>
<tr>
<td>Crotch depth</td>
<td>9.53</td>
<td>9.45</td>
<td>10.44</td>
<td>9.74</td>
<td>10.63</td>
</tr>
<tr>
<td>Waist girth</td>
<td><strong>33.1</strong></td>
<td><strong>33.02</strong></td>
<td><strong>33.01</strong></td>
<td><strong>32.67</strong></td>
<td><strong>33.5</strong></td>
</tr>
<tr>
<td>Hip girth</td>
<td>36.78</td>
<td>36.74</td>
<td>35.48</td>
<td>36.22</td>
<td>38.5</td>
</tr>
</tbody>
</table>

The virtual pants simulated with the shape-driven block pattern on the fit tester from the Flat-Straight body shape group is shown in Figure 4.39a and the pants with a single block pattern developed based on ASTM measurements on the same fit tester is shown in Figure 4.39b. Visual comparison of the fitting of the pants using display unique color and springs mode indicated that the virtual pants simulated with the ASTM single block pattern have noticeable fitting issues at the center front and back crotch inseam ease, front and back waistline. Also, the gap below the back seat indicated the unfitted center back inseam slope and crotch extension.

Virtual pants simulated with the shape-driven block pattern of the Curvy-Straight body shape group on the fit tester with same body measurement from the Moderate Curvy-Straight body shape was shown in Figure 4.39c. Using the shape-driven block pattern of the Flat-Straight body shape group on the Moderate Curvy-Straight body shape that has a longer height from waist to crotch resulted in misplacement of the waist line in both the front and back. Also, the different back seat angle caused wrinkle and gaps below the back seat. In the Flat-Straight body shape group, the proportion of the front piece is almost equal to the back piece, however, the
Moderate Curvy-Straight body shape group has more fat in the front compared to the Flat-Straight body shape group. The discrepancy between the shape driven pattern’s and the actual fit tester’s front and back proportions, resulted in tilted side seams for the simulated pants on the Moderate Curvy-Straight body shape fit tester.

Figure 4.39d illustrated simulated virtual pants with the shape-driven block pattern of the Flat-Straight body shape group on the fit tester with same body measurement from the curvy body shape. The most significant fitting issue in this case, more pronounced at the back, was the misplacement of the waist line. The curvy body shape needs more room at the back to accommodate for the rounded buttocks, while the Shape-driven pattern of the Flat-Straight group was developed for flat buttocks, therefore, the fit tester from the curvy body shape experienced fit problems at the front and back waist line, front and back inseam ease, and side seam placement.
Figure 4.39. (a, c, d) Comparison of the virtual pants simulated with shape-driven block pattern of the Flat-Straight body shape group on fit testers from (a) the Flat-Straight group, (c) the Moderate Flat-Straight group, (d) the Curvy body shape group. (b) Simulated virtual pants with block pattern developed based on current ASTM measurements.
4.6.2 Comparison of fit of the pants from shape-driven block pattern and a single block pattern for the moderate Curvy-Straight body shape group

Three fit testers from each body shape group, with approximately the same body measurements as of the measurements of the fit model that was used to develop the shape-driven block pattern for the Moderate Curvy-Straight group, were selected for the validation phase. The average value of each factor for this body shape category as well as the factor values of the three fit testers were listed in Table 4.24.

Table 4.24. Average factor values of the Moderate Curvy-Straight group and the factor values of the three selected fit testers

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Moderate Curvy-Straight Body Shape Fit Testers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fit Tester 1 from Flat-Straight (#169)</td>
</tr>
<tr>
<td>Girth Factor</td>
<td>-0.71</td>
<td>-1.64</td>
</tr>
<tr>
<td>Height &amp; Length Factor</td>
<td>1.32</td>
<td>-0.72</td>
</tr>
<tr>
<td>Depth &amp; Angle Factor</td>
<td>0.37</td>
<td>-1.00</td>
</tr>
</tbody>
</table>

Furthermore, Table 4.25 includes the primary body measurements of the three fit testers and the fit representative of this body shape category. As the size of fit model of the Moderate Curvy-Straight body shape group was 39, all the fit testers were also selected from size 39. Also, the body measurements of size 39 of the ASTM were used to draft a pattern using Armstrong’s (2005) instructions.
Table 4.25. Primary body measurements for the three selected fit testers and the fit model from the Moderate Curvy-Straight group

<table>
<thead>
<tr>
<th>Fit Model</th>
<th>Fit Testers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fit tester 1 from Flat-Straight</td>
</tr>
<tr>
<td></td>
<td>(#169)</td>
</tr>
<tr>
<td></td>
<td>Fit tester 2 from Moderate Curvy-Straight</td>
</tr>
<tr>
<td></td>
<td>(#357)</td>
</tr>
<tr>
<td></td>
<td>Fit tester 3 from Curvy</td>
</tr>
<tr>
<td></td>
<td>(#730)</td>
</tr>
<tr>
<td>Height</td>
<td>64</td>
</tr>
<tr>
<td>Waist to ankle</td>
<td>42.5</td>
</tr>
<tr>
<td></td>
<td>36.10</td>
</tr>
<tr>
<td></td>
<td>38.31</td>
</tr>
<tr>
<td></td>
<td>35.67</td>
</tr>
<tr>
<td>Crotch depth</td>
<td>10.44</td>
</tr>
<tr>
<td></td>
<td>8.85</td>
</tr>
<tr>
<td></td>
<td>11.02</td>
</tr>
<tr>
<td></td>
<td>9.64</td>
</tr>
<tr>
<td>Waist girth</td>
<td>33.01</td>
</tr>
<tr>
<td></td>
<td>32.82</td>
</tr>
<tr>
<td></td>
<td>33.53</td>
</tr>
<tr>
<td></td>
<td>31.58</td>
</tr>
<tr>
<td>Hip girth</td>
<td>34.43</td>
</tr>
<tr>
<td></td>
<td>34.71</td>
</tr>
<tr>
<td></td>
<td>35.24</td>
</tr>
<tr>
<td></td>
<td>34.99</td>
</tr>
</tbody>
</table>

The virtual pants simulated with the shape-driven block pattern on the fit tester from the Moderate Curvy-Straight body shape group is shown in Figure 4.40a and the pants with a single block pattern developed based on ASTM measurements on the same fit tester is shown in Figure 4.40b. Visual comparison of the fitting of the pants using display unique color and springs mode indicated that the virtual pants simulated with the ASTM single block pattern had apparent fitting issues at the front and back waistline. Also, wrinkles radiated form the center front and back crotch inseam were very noticeable. The gap below the back seat and front crotch indicated the unfitted crotch extension for this body shape.

Virtual pants simulated with the shape-driven block pattern of the Moderate Curvy-Straight body shape group on the fit tester with same body measurement from the Flat-Straight body shape was shown in Figure 4.40c. Different back seat angle caused wrinkle and gaps below the back seat. In the Flat-Straight body shape group, the proportion of the front piece is almost equal to the back piece, however, the Moderate Flat-Straight body shape group has more fat in the front compare to the Flat-straight body shape group. The discrepancy between the shape
driven pattern’s and the actual fit tester’s front and back proportions, resulted in tilted side seam for the simulated pants on the Moderate Flat-Straight body shape fit tester.

Figure 4.40d illustrated simulated virtual pants with the shape-driven block pattern of the Moderate Curvy-Straight body shape group on the fit tester with same body measurement from the curvy body shape. The curvy body shape needs more room at the back to accommodate for the protruding buttocks, while the Shape-driven pattern of the Moderate-Straight group was not developed for this body type, therefore the virtual pants were left unstitched at side seams. Also, the side seam at the hip level was swayed back.
Figure 4.40. (a, c, d) Comparison of the virtual pants simulated with shape-driven block pattern of the Moderate Curvy-Straight body shape group on fit testers from (a) the Moderate Curvy-Straight group, (c) the Flat-Straight group, (d) the Curvy body shape group. (b) Simulated virtual pants with block pattern developed based on current ASTM measurements.
4.6.3 Comparison of fit of the pants from shape-driven block pattern and a single block pattern for the Curvy body shape group

Three fit testers from each body shape group, with approximately the same body measurements as of the measurements of the fit model that was used to develop the shape-driven block pattern for the Curvy group, were selected for validation phase. The average value of each factor for this body shape category as well as the factor values of the three fit testers were listed in Table 4.26. Also, the body measurements of the selected fit testers were summarized in Table 4.27.

Table 4.26. Average factor values of the Curvy group and the factor values of the three selected fit testers

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Curvy Body Shape Fit Testers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fit Tester 1 from Flat-Straight (587)</td>
</tr>
<tr>
<td>Girth Factor</td>
<td>0.78</td>
<td>-0.41</td>
</tr>
<tr>
<td>Height &amp; Length Factor</td>
<td>-0.024</td>
<td>-0.79</td>
</tr>
<tr>
<td>Depth &amp; Angle Factor</td>
<td>0.21</td>
<td>-0.80</td>
</tr>
</tbody>
</table>

Furthermore, in Table 4.27 includes the primary body measurements of the three fit testers and the fit representative of this body shape category. As the size of the fit model of the Curvy body shape group was 37, all the fit testers were also selected from size 37. Also, the body measurements of size 37 of the ASTM were used to draft a pattern using Armstrong’s (2005) instructions.
Table 4.27. Primary body measurements for the three selected fit testers and the fit model from the Curvy group

<table>
<thead>
<tr>
<th></th>
<th>Curvy Body Shape Group</th>
<th>Fit Testers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fit Model</td>
<td>Fit tester 1 from Flat-Straight</td>
</tr>
<tr>
<td></td>
<td>(#587)</td>
<td>(#274)</td>
</tr>
<tr>
<td>Height</td>
<td>73</td>
<td>65</td>
</tr>
<tr>
<td>Waist to ankle</td>
<td>40.7</td>
<td>40.93</td>
</tr>
<tr>
<td>Crotch depth</td>
<td>10.29</td>
<td>9.05</td>
</tr>
<tr>
<td>Waist girth</td>
<td>31.57</td>
<td>31.99</td>
</tr>
<tr>
<td>Hip girth</td>
<td>36.93</td>
<td>35.72</td>
</tr>
</tbody>
</table>

The virtual pants simulated with the shape-driven block pattern on the fit tester from the Curvy body shape group is shown in Figure 4.41a and the pants with a block pattern developed based on ASTM measurements on the same fit tester is shown in Figure 4.41b. Visual comparison of the fitting of the pants using display unique color and springs mode indicated that the virtual pants simulated with the ASTM single block pattern have evident fitting issues at the front and back waistline, crotch, and the side seam. Also, wrinkles radiated from the center front crotch inseam were very noticeable.

Virtual pants simulated with the shape-driven block pattern of the Curvy body shape group on the fit tester with same body measurement from the Flat-Straight body shape was shown in Figure 4.41c. The wrinkles and gap below the back seat resulted from the fact that the pattern was designed for the Curvy group, that has a large back seat angle, while the fit tester belongs to the Flat-Straight group with a much smaller back seat angle. Similar to the situation discussed for the Moderate Curvy-Straight group above, the discrepancy between the shape driven pattern’s and the actual fit tester’s front and back proportions, resulted in misplacement of the side seam at the hip level as the seam was swayed away from the actual side seam.
Figure 4.41d illustrated simulated virtual pants with the shape-driven block pattern of the Curvy body shape group on the fit tester with same body measurement from the Moderate Curvy-Straight body shape. The Moderate Curvy-Straight body shape does not need as much room as the Curvy body shape at the back. Therefore, the gaps and wrinkles emerged below the back seat.

Overall, fitting of the virtual pants simulated with the shape-driven block pattern on the same body shape group provided better fit compare to the simulated pants on other body shape groups and the ones which were based on ASTM measurements. In terms of front and back waistline placement, the front and back lines of the virtual pants, which were made with the shape driven block pattern for the same body shape group as the body shape group of the teste, were aligned with the waist of the fit tester. However, the front and back waist line of the virtual pants that were simulated on fit testers, that belonged to groups other than that of the shape driven block pattern, were relatively pulled down or relocated. As far as front and back crotch inseam ease is concerned, the virtual pants made with the shape-driven block pattern of the same body shape group were found to fit better on the corresponding body shape as compared to simulations on fit testers belonging to other body shape groups.
Figure 4.41. (a, c, d) Comparison of the virtual pants simulated with shape-driven block pattern of the Curvy body shape group on fit testers from (a) the Curvy group, (c) the Flat-Straight group, (d) the Moderate Curvy-Straight body shape group. (b) Simulated virtual pants with block pattern developed based on current ASTM measurements.
CHAPTER 5. CONCLUSION

This chapter summarizes the finding of the study and answers the research questions. It discusses the limitations of the study and provide suggestions for additional research in this area.

5.1 Summary and Conclusion

There are various issues that prevent the apparel industry from providing well-fitted garments. These include the lack of current anthropometric measurements, lack of accurate pattern grading methodology for mass production, and lack of information regarding fit needs for different body shapes, and also developing basic block pattern based on a single fit model (Ashdown & Dunne, 2006; Ashdown, 2014). The overall purpose of this study was to investigate the need for a different pants block pattern for each body shape identified from the data, in the context of the segmentation of the Theory of Inventive Problem Solving (TRIZ). More specifically, the goal of the study was improving the overall fit of male’ jeans by categorizing the body shapes of males aged 18-35 and develop basic block patterns for each identified body shape group. The specific objectives for this study were to:

- Categorize a sample of male body shapes using statistical analysis
- Develop basic pants block pattern for each identified body shape by fitting one representative man from each group
- Use 3D virtual fitting technology and map tension to assess the fit
- Compare the fit of the pants created from basic block pattern (single base pattern) with pants developed with shape-driven blocks
The research question that were developed to achieve the purpose and objective of this study were:

RQ1: How are fit issues related to each body shape group?

RQ2: What is the relationship between men’s body shape and shape of the block pattern?

RQ3: How does the shape of the basic blocks created for each body shape compare to one another?

RQ4: Can the fit needs of more than one men’s body shape be accommodated by the same/single shape pattern block?

RQ5: Does the shape driven block provide a better fit than the block created from standard methods?

5.1.1 Body shape categorization

In phase one, a quantitative research method design was used to categorize lower the body shape of men aged 18-35; and develop a block pants pattern with an acceptable fit for each identified body shape group. The blocks were examined to uncover if a single block can accommodate the fit needs of two or more men’s body shapes. The study started with 1,763 subjects in the 18-35 age range obtained from SizeUSA data. However, to obtain reliable body shape categorization, individuals with BMI over 30 were excluded from the study resulting in 1,420 effective subjects. The Exploratory Factor Analysis (EFA) approach was utilized for the body shape categorization. Among the initial 70 body measurements, only those that were either useful for drafting pants blocks or the measurements that could define the silhouette and shape of the body, were selected to feed into the Factor analysis process. Through the EFA work and examining the correlation matrix, the number of measurements used in this study were further reduced to make sure none of the remaining measurements are highly correlated. The EFA
resulted in three factors namely, girth factor, height & length factor and depth and angle factor. Circumferential proportions are the only measurements that are often used for body categorization methods. Such body shape categorization approaches suffer from the lack of differentiation between two bodies with the same circumference measurements while having different depths (Petrova & Ashdown, 2008; Simmon et al., 2004). The inclusion of depth and angle measurements in the third factor and height and length in second factor enabled us to overcome this problem in a similar way as the path taken by Song and Ashdown (2011). Past research investigating women’s body shape categorization, excluded the length measurements from the analysis due to their high mutual correlation (Song & Ashdown, 2011). However, in this study height and length measurements were found to contribute considerably to men’s body shape categorization as they were encapsulated in the factor 2.

In this research three body shape categories for men were identified through cluster analysis. The number of clusters was an initial value that was pre-determined by the user and fed into the Cluster Analysis program of SPSS. The inclusion of sufficient subjects and the Cluster Analysis convergence criterion number were the two decisive factors considered for selecting the appropriate number of clusters which turned out to be three in this study. The three men’s body shapes categories determined in this study were named by the researcher as Flat-Straight, Moderate Curvy-Straight and Curvy following the values of different body measurement represented by the three factors.

After an exhaustive search and review of the available literature the only studies investigating men’s body shape categorization that were found were either conducted on whole body (Sheldon, 1940; Chun, 2007) or upper body (Shin et al., 2011). Whereas this dissertation
focused on the lower body shape categorization, therefore no appropriate previous work was found for comparative discussion.

5.1.2 Develop shape-driven block pattern for each body shape group

The focus of the second phase of this study was the development of pattern blocks for each identified body shape. Optitex 3D was used for the pants simulation and virtual fit assessment once patterns were drafted. As far as RQ1: How are fit issues related to each body shape group? is concerned, some fitting issues such as crotch extension and shape were found to be common among all the three clusters, while there were also exclusive fitting issues exclusive to a particular body shape. For example, the initial drafted pattern that was simulated on all the three identified body shapes cause loose areas in the waist and hip level only for the Flat-Straight group, but not for the other two categories. On the other hand, in the Moderate Curvy-Straight and Curvy body shape groups the pants were found to be too tight on the hip and waist levels. This was due to the larger depth and angle factors found in these two groups. These findings are consistent with Beazley and Bond (2003) assertion that “measurements alone do not reflect the total body shape” (p. 25). In another study on pants pattern making for women (Mckinney et al., 2017) observed a direct relation between body crotch shape and the choice of appropriate block pattern. This finding is consistent with the conclusion regarding the first research question. Therefore, in answer to RQ1: How are fit issues related to each body shape group? this research found that while there exist a number of common fit issues among all body shapes, there are certain fit problems that would exclusively appear for specific body shape(s).

Different fit issues required exclusive fit alterations, which ended up having to distinguish body shape-driven block patterns. The silhouette of the Shape-driven block patterns
was compared to answer RQ2: What is the relationship between men’s body shape and shape of the block pattern? Comparison of the shape-driven block pattern of each body shape group revealed that the shape of the block patterns was highly correlated with the shape of the body. It was found that the shape-driven block patterns were noticeably different in five areas: (a) height from waist to crotch, (b) back crotch inseam slope, (c) silhouette of the side seam, (d) center front inseam slope, and (e) crotch extension. For instance, the clear difference in the waist to crotch height observed in the waist to crotch measurements of the three clusters was clearly reflected in the appearance of the shape-driven block patterns. It was also found that the Curvy body shape had the highest slope of back crotch inseam, which was consistently the most prominent buttock implied by the high back seat angle values observed for this body shape category. The silhouette of the side seam was found to be straight for the Flat-Straight group and the Curvy body shape category had the curviest side seam. Furthermore, center front inseam slope was found to have the highest slope which was consistent with the largest value of depth variable measured for the same group. Therefore, in answer to RQ2: What is the relationship between men’s body shape and shape of the block pattern? This research found that the pattern and body shapes are highly correlated, which supports McKinney et al. (2016) assertion that the garment shapes and body shapes are interrelated.

In answer to RQ3: How does the shape of the basic blocks created for each body shape compare to one another? The three developed block patterns had noticeable differences which were also partly addressed while RQ2 was discussed such as differences in height from waist to crotch, back crotch inseam slope, silhouette of the side seam, center front inseam slope, and crotch extension. Moreover, one could also distinguish the block patterns based on their differences in back to front proportions at hip and waist levels. As far as back to front proportion
at waist level is concerned, the Moderate Curvy-Straight category was the only group that had a proportion measurement with a value smaller than one (0.95) while the other two body shape driven block patterns had proportions larger than one (1.3 and 1.1 for the Flat-Straight and Curvy groups respectively). This indicated a more pronounced distribution of fat in the front piece for the Moderate Curvy-Straight group as compared to the other two body shapes. On the other hand, the hip level back to front proportion had its largest value for the Curvy group (1.3) as compared to the Flat-Straight and Moderate Curvy-Straight groups which both had the back to front proportion value of 1.1. This was expected given the prominent buttocks of the Curvy body shape group.

5.1.3 Validation of shape-driven block patterns

In phase 3, the shape-driven block patterns that were developed in phase 2 were validated. In this stage the shape driven pattern of body shape group A was simulated on fit testers with the same waist measurement selected from all the three (A, B and C) shape categories. Furthermore, a single block pattern that was developed using ASTM measurements with the same waist size was simulated on the fit tester of body group A. The whole process was then repeated for the other two shape categories, B and C, adding up to total of 12 (3×4) simulations. After careful examination of each simulation, it was found that shape driven patterns revealed minimum fit issues once they were tried on fit testers belonging to the same body shape group. On the other hand, the patterns that were simulated on fit testers from categories other than their exclusive body shape group, faced various fit issues such as misplacement of front and back waist line and waist to hip side seam, as well as emergence of wrinkles and gaps below the back seat and radiation of drag lines from back and front crotch inseam. Similar fit issues with even more
intensity were found when the single pattern based on ASTM measurements was simulated on the fit testers. The results of validation of the shape driven block patterns clearly concluded that the body shape affects the fit of the pants. Each body shape group has its own fit needs, which is consistent with the assertion provided in the existing literature (Connell et al., 2006; Connell & Ulrich, 2005; Vuruskan & Bulgun, 2011; Romeo, 2013). Also, this study found that individuals’ sizes and body shapes are not related and persons within same size category do not necessarily have the same body shape, which confirms Mossiman’s shape analysis theory (1988). To answer the RQ4: Can the fit needs of more than one men’s body shape be accommodated by the same/single shape pattern block? This study found that that a single block pattern certainly cannot address the fit needs belonging to all the body shape categories and it is vital to consider the physical differences among different body shapes to improve the fitting of pants.

Furthermore, by comparing the fitting of the virtual pants of the shape driven block patterns with the virtual pants of the single block patterns simulated on the fit testers, one was able to address the RQ5: Does the shape driven block provide a better fit than the block created from standard methods? As the shape driven block patterns lead to significantly less fit issues as compared to the single block patterns developed based on ASTM standards. This conclusion was quite sensible as the examination of ASTM measurements charts show that the body shape factor was not considered in developing sizing system, and size charts were developed based on regular body shape that do not consider any information regarding consumer’s body shape (ASTM, 2012; Pisut & Connell, 2007).

To sum up, this study concluded shape driven-block pattern provided better fitting compare to the single block pattern. Based on the segmentation principle of the TRIZ theory by
implementing shape-driven block pattern, one of the fit issues facing the apparel industry in its transition to mass customization can be eliminated.

5.2 Limitation and Strength of the Study

It is very important to mention that this study did not claim that one would be able to achieve the ultimate perfect fit by using shape-driven block patterns while it asserted that one can obtain appropriate fit with lesser fitting sessions using shape driven block pattern in comparison to standardized single block pattern.

Some limitations were presented in this study. As noted by Sayem (2017) virtual apparel fitting is still an emerging technology and the current tension map technology is affected by pattern piece positioning. This study confirmed several issues still exist with tension mapping, notable examples are listed in the following. When simulating apparel on an avatar it is very important to make sure that the garment piece does not have any collision points with the body. This requires that when beginning the simulation, the garment pieces are positioned at a proper distance from the body. However, even with careful obedience of the above-mentioned rules, it is still very difficult to obtain identical tension map results in consecutive repetitions. Piece positioning indeed had a noticeable effect on the final outcome. For instance, even a small change in the value of curvature applied to the pattern pieces would result in a noticeable change in the tension map. It is also very crucial to make sure that the pattern pieces have zero overlap before the onset of simulation as any initial overlap would either overestimate or underestimate the tension map matrix.

Finally, through the simulation stage, it was found to be very difficult to map the fit issue identified in 3D simulation, to changes required on the 2D pattern. Two variables that were
outside of the researchers control were identified as contributing to this issue: (1) the stance of
the individual when the 3D body scan was taken, and (2) the garment worn by the individual
when the 3D body scan was taken.

The first variable, the stance of the individual, was found to create wrinkles in leg area of
the pant block as shown in Figure 4.15 and Figure 4.19. The second issue related to the 3D body
scan was the garment worn by the individual during the 3D body scan. Inaccuracies in fitting the
garment would occur due to wrinkles that were present in the under garment worn during the 3D
body scan (see Figure 4.20). These two issues underscore the importance of an accurate 3D body
scan to proper fitting of garments. The apparel industry wants to advance technology to the
point that the customer can take their own scan at home and order a mass customized garment
from their scan. The 3D body scans used for this research were taken by trained researchers and
yet two issues occurred during the scanning process that affected the proper fitting of the pattern
block.

The cost and time involved in fitting prototype garments has been a major issue for the
apparel industry. Song (2011) found that to achieve an acceptable fit each fit model had to have 3
to 5 fitting sessions. However, with the aid of technology such as body scanner and virtual
prototyping, a designer can conduct as many virtual try on as needed to achieve the proper fit.
Fitting pants is very complicated. While this research uncovered fitting issues related to different
body shapes each consumer is an individual and may and may not receive the proper fit by
applying only changes to the basic block that have been identified for their body shape category.

Another limitation of this study was that the researcher did not have access to all the features
of the Optitex 2D/3D such as drape to fit, which restricted the researcher from designing
obtaining the optimized shape-driven block pattern for each body shape through further detailed modifications.

The accusation of a large (1420 male) and diverse population including four different ethnic groups (white, black, Hispanic, and other) as well as different ethnic categories contributed to the strength of this study. Also, categorization of the body shapes was carried out using the powerful Exploratory Factor Analysis (EFA) and cluster analysis statistical tools, which has more accuracy compared to other methods of categorization based on visual assessment or circumference proportion measurements. In the visual assessment method, the side and front views could not be casted simultaneously. On the other hand, the proportional method suffered from inability to distinguish between two bodies with the same proportions but different depth and width measurements.

Another strength of this study was the acquisition of actual 3D avatar rather than creating avatar by applying body measurements to the software’s default avatar. Different studies found that the garment simulation on the direct avatar are more accurate and realistic than parametric avatar (Lim, 2009; Lim & Istook, 2012; Jevsnik, Pilar, Stjepanovic, & Rudolf, 2012). However, the static pose of the avatar made it difficult to check the fitting of the pants from side view as the side seam was masked with hands. But, in this study, the researcher was able to check the fitting of the pants from side view through the holes created by missing data (Figure 4.35).

Using an individual’s avatar generated from their 3D body scan takes the research from a strictly theoretical academic approach to a real-world application of the technology. At this
point in the technologies development applied research is necessary for the apparel industry to progress to mass customization.

5.3 Future Studies

There are several areas in which future research should be conducted. In the following section, these areas are briefly pointed out and discussed. This study examined the overall fit of male jeans, specifically in the waist to hip area, and does not claim detailed investigation of fit issues of other lower body areas such knee and thigh areas. A more comprehensive and detailed study would require a collaborative work that includes experienced pattern makers and fit developers. For example, during the virtual try-on stage of this work several fitting issues at tight areas were found while the tight measurements were excluded from the EFA body categorization analysis at the first place.

Obese subjects with BMI over 30 were not included in this research, as 3D body scanning cannot accurately measure the crotch depth in obese subjects which is a vital measurement for pants pattern drafting. According to Center for Disease Control (2018) the prevalence of obesity among adults in the age range of 20-39 is about 34.8% which makes a very noticeable portion of the population. Therefore, it is imperative that researchers investigate and explore ways to include obese population in body shape categorization and ultimately development of shape driven block patterns.

The limited research on men’s clothing fit concludes dissatisfaction with current upper body apparel due to lack of knowledge regarding proper fit and body proportion (Sindicich & Black, 2011; Chattaraman et al., 2013). Therefore, it is suggested to adopt a similar methodology as the approach of this thesis to categorize upper-body shapes in men’s population and eventually
develop shape driven block patterns for men’s upper body shape. It is also noteworthy that, virtual prototyping is still an emerging technology and cannot fully replace the conventional prototyping as there are technical issues for simulation that related to the utilization of actual avatars. Therefore, it would be very helpful to expand the scope of this study to investigate the fitting of the shape driven patterns on actual models.
References


Chun, J. (2007). Communication of Sizing and Fit In S. P. Ashdown (Ed.), Sizing in clothing:
developing effective sizing system for ready-to-wear clothing (pp. 220-245). Boca Raton, FL: Woodhead Publishing Limited


Appendix A: The SizeUSA Agreement

Conditions and Limitations for Use of Licensed SizeUSA Data

Background
[TC] conducted a national survey of the adult population of the United States using its 3D whole body scanner. The database of statistically significant samples of the population is comprised of multiple components:
- An anonymous demographic survey with age, income, ethnicity, gender, height, weight, employment, education level, activity level, zip code, and preferred garment size (where known)
- Three-dimensional scan data on each subject
- Measurements extracted from 3D scan data

The Licensed Data
- All demographic data is anonymous and cannot be tied to any personally identifiable information.
- 3D scan data is provided in [TC] Labs LLC proprietary scan format, requiring [TC] Labs LLC's scanner software to open the data and extract measurements.
  - If the purchaser does not have access to [TC] Labs LLC's scanner software, standalone software, with a permanent license, is available for sale.
- Measurements extracted from scan data will be provided as Microsoft Excel spreadsheets, allowing all analytical and mathematic operations normally available with Microsoft Excel.
- Custom analysis of data from 3D scans will be performed by [TC] Labs on a proprietary basis. Clients who wish to have customized, proprietary analysis will be provided a quotation for services to be performed by [TC] Labs.

Restrictions on Use
- The 3D scan data, survey data, and measurements are intended solely for use within the company that has licensed the data through sponsorship or purchase.
- The licensee agrees not to copy or redistribute the reports, images, or data all or in part outside the licensee’s company. The licensee may perform analysis to support its business processes and use that analysis with its customers and suppliers.
- Data purchased by sponsors or clients may be used internally by purchasers, and may be used in business relationships with suppliers and/or customers, but the data may not be provided to suppliers or customers in any form.
- Consultants and others, who may perform services for fee or in exchange for other consideration, may use the data to perform analysis for clients and/or customers, but are prohibited from sharing the source data in any form. Analysis and recommendations based on analysis of the data are not restricted in use. Consultants dealing to use SizeUSA data on behalf of a client must purchase the data for the client, if the client is not a sponsor or license holder, or are otherwise in possession of a legal copy of the data. Consultants, who are in legal possession of the data or fraction thereof for use in their consulting practice, are prohibited from using the measurement data for an unlicensed client. The client must have full rights to use data, even if a third party performs work.
- Consultants engaged by the sponsor or licensed client, to perform customized analysis on behalf of the sponsor or licensed client, may use data acquired by sponsors or clients under the sponsorship or licensed agreement. Sponsor is obligated under the terms of the sponsorship agreement to ensure that the information provided to any consultant is protected from re-use or distribution by the consultant. Sponsor should take at least as much care as would be used in protecting their own proprietary interests. Licensed clients are expected to follow the same requirements as sponsors.
- Violations of this agreement will result in the SizeUSA license being voided and potential legal remedies.

I agree to the terms of this agreement by signing below.

Name: Elke Saraštis
Title: Graduate Student
Company: Louisiana State University
Date: 3.2.2018
Appendix B: Institutional Review Board Approval

ACTION ON EXEMPTION APPROVAL REQUEST

TO:        Elahe Saeidi  
Textile Apparel & Merchandising

FROM:      Dennis Landin  
Chair, Institutional Review Board

DATE:      September 6, 2018

RE:        IRB# E11178

TITLE:     Men's Jeans Fit Based on Body Shape Categorization


Review Date: 9/6/2019

Approved X Disapproved

Approval Date: 9/6/2019 Approval Expiration Date: 9/5/2021

Exemption Category/Paragraph: 4a

Signed Consent Waived?: N/A

Re-review frequency: (three years unless otherwise stated)

LSU Proposal Number (if applicable):

By: Dennis Landin, Chairman

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
8. SPECIAL NOTE: When emailing more than one recipient, make sure you use bcc. Approvals will automatically be closed by the IRB on the expiration date unless the PI requests a continuation.

* All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb
VITA

Elahe Saeidi was born in Shiraz, Iran. She earned a Bachelor of Computer Science degree at Shiraz Azad University in Iran, 2007. After graduation, she worked as a sale manager and computer instructor for three years. In 2012, she entered the Master Program at The University of Alabama to pursue her dream and study apparel design. In 2015, she was accepted as a PhD student at Louisiana State University. Her research interests include: fit and sizing of clothing, the use of 3D body scanning in the apparel industry, custom-made clothing developed by automated made-to-measure system, issues of patternmaking, virtual fit, subjective and objective fit assessment, and technical design.