ABSTRACT

KHAIRNAR, ANUJA ANIL. Reducing the Fit Variation in Denim Jeans Manufacturing (Under the direction of Dr. Helmut Hergeth & Dr. Lori Rothenberg).

VF Jeanswear had a decline in sales and suspected a few major reasons as the cause. Fit consistency was one of the key reasons. This thesis demonstrates how the fit inconsistency was proven with the existing data. It further goes into using Lean six sigma tools to define the problem and work towards identifying the underlying reasons for fit inconsistency.

In the define phase the problem was identified and the further the measurement metric was determined. Multiple experiments were designed to understand the variation in processes, fabric types and chemicals used. These experiments also helped understand which process had the most impact.

Once the process and factors with the most impact were found, recommendations and changes were made to improve them and thus result in a better overall fit consistency.

Some manufacturers of denim jeans are experiencing a decline in sales. One of the possible reasons for this decline is the lack of consistent fit for jeans. The purpose of this thesis was to reduce the variation in the fit of jeans for one of the largest jean's manufacturers, VF Jeanswear. The methodology used was Lean Six Sigma. After defining the problem, baseline data were collected on the manufacturing process. Using the baseline data, the root cause of the problem was identified. Solutions to the problem were designed and implemented and then the success of the solutions were measured.

The results of the study indicated that by increasing the Tri-Blends and Bi-Blends shrinkage Testing from 30% to 100% the variation in fit consistency was reduced by 23% in men's and 12.5% in women's jeans. Future research needs to be done on working with mill closely to understand fabric variation and study the chemicals in wash recipes for minimal shrinkage.

Understanding the Reasons for Fit Variation in Manufacturing of Denim jeans and ways to reduce Fit Variation

by
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DEDICATION

This thesis is dedicated to my parents, Rekha and Anil Khairnar and my family and friends for their constant support and encouragement.

BIOGRAPHY

Anuja Khairnar comes from a city called Mumbai in India. The city is known as the financial capital of the country and has a population of 18.5 Million.

She earned her Bachelor's in Fibers and Textiles Processing Technology from Institute of Chemical Technology, Mumbai in 2017. She was determined to study further and pursue her higher education abroad which brought her to Raleigh, North Carolina at NC State Wilson College of Textiles, the most renowned university for textiles. She got an excellent opportunity to work with VF Corporation and complete her master's thesis under the guidance of Dr. Helmut Hergeth and Dr. Lori Rothenberg.

She successfully completed her Summer internship with Hollander Sleep Products, Boca Raton and a 7-month long internship with VF Corporation to complete her thesis project. She wishes to work in the United States of America in the future.

ACKNOWLEDGMENTS

I would really like to thank Dr. Helmut Hergeth and Dr. Lori Rothenberg for giving me the opportunity to work under their guidance. They were always there to help me out during the course of this project. Not only did they provide me with useful insights every time I approached them, they also helped me do better in my internship.

I would also like to thank Dr. Peter Hauser for giving his time to this and all helpful insights during the meetings.

I would also like to express my gratitude to James Booth from VF Corporation, for providing me this amazing opportunity of working with the company on this project. A special thanks to Christian Woodman and the Team in Acanceh, Mexico for their constant support during the visits to the facilities and after.

I am thankful to the College of textiles to provide me with all the resources and to my family for encouraging me and supporting me to pursue higher education in a country so far from home. I am grateful to my friends for their constant help and motivation.

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CHAPTER 1: Introduction

1.1 Introduction to the research

Among all the textile products, no other fabric has received such a wide acceptance as denim. It has been used extensively by people of all ages, classes and genders. Denim is a hard and durable warp faced 3/1 twill cotton fabric, woven with indigo dyed warp and white filling yarns, having weights of 14½ ounces per square yard. It has been in use for over a century in the clothing industry, especially in the manufacture of overalls and trousers for hard labor, demonstrating its durability, which along with its comfort made denim jeans extremely popular for leisure wear, too. From the seventeenth century to the present day, denim has been used for making trousers, upholstery and awnings, and has been found in museums, attics, antique stores and archaeological digs. It is also considered the fabric of hard work, expression of youth rebellion and the favorite of American cowboys.(Paul, 2015b)

Figure 1: Denim Jeans Stacked on Shelf ("Retail Sales Tip:It's Not About How Neatly Your Merchandise Is Stacked," n.d.)

Denim jeans pass through many processes during manufacturing including washing and dry finishing with a laser to provide an attractive and fashionable look. Unfortunately, during finishing treatments denim garments lose their dimensional stability causing many difficulties with pattern adjustment before cutting the fabric. This affects the ability to obtain fixed sizes with defined measurements.(Dhouib, Khedher, & Sakli, 2016).

The purpose of the study in this paper is to reduce the existing fit variation in a Denim Manufacturing company called VF Corporation. They have been showing decline in sales and fit being a major contributor, there is a good chance of improving it.

This study will help the company to understand their variation better and take small steps towards gradually reducing and eventually eliminating them.

1.2 About VF Corporation

“ VF Corporation outfits consumers around the world with its diverse portfolio of iconic lifestyle brands, including *Vans®*, *The North Face®*, *Timberland®*, *Wrangler®* and *Lee®*. It was founded in 1899, and has become one of the world’s largest apparel, footwear and accessories companies.”

Figure 2: VF Corporation Logo**(“Our Company :: VF Corporation (VFC),” n.d.)**

“They are socially and environmentally responsible and have operations that span numerous geographies, product categories and distribution channels.” (“Our Company :: VF Corporation (VFC),” n.d.)

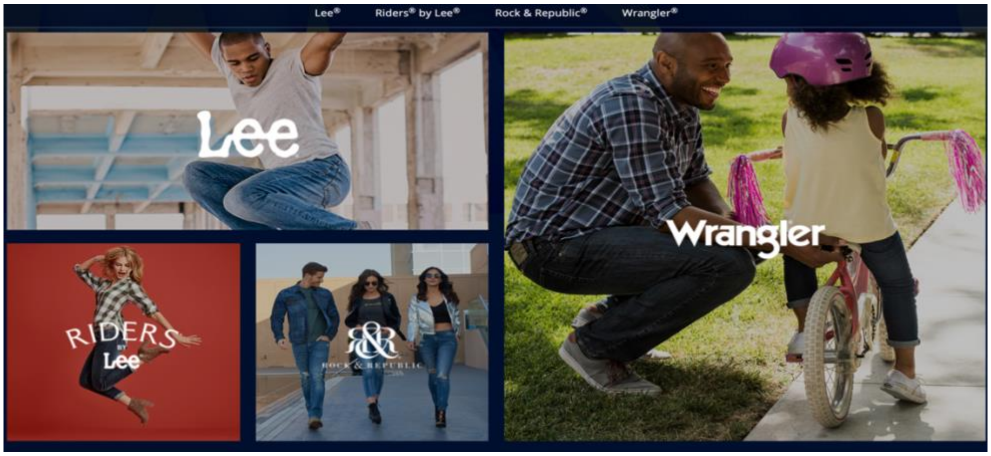

Figure 3: Different Jeanswear Brands**("Our Company :: VF Corporation (VFC)," n.d.)**

Figure 4: History of VF Corporation**("Our Company :: VF Corporation (VFC)," n.d.)**

VF has a powerful business model and their move towards constantly improving themselves helps give them a competitive edge.

1.3 DMAIC: A Lean Six Sigma Methodology

The Six Sigma DMAIC process (define, measure, analyze, improve, control) is an improvement system for existing processes falling below specification and looking for incremental improvement.

DMAIC is a basic data driven problem-solving methodology. It has five steps which are: Define, Measure, Analyze, Improve and Control. This methodology is simple yet powerful. It can be thought of as a roadmap towards process improvement by means of quality management and statistical tools. DMAIC projects strive to reduce variation so that the improved target for be thought of as a roadmap towards process improvement by means of quality management and statistical tools. DMAIC projects strive to reduce variation so that the improved target for performance can be achieved.

Definitions

Greige Fabric: Greige is an unfinished woven or knitted **fabric** that has not been bleached or dyed. It can be used for upholstery, window treatments, clothes and more.

Opening: The process of opening up the cotton fibers and aerating them.

Blending: The process of mixing two types of fibers with each other in a particular ratio

Carding: Fibers are opened to more or less single fibers. Dust, dirt, neps are removed here

Drawing: The process of attenuating the loose assembly of fibers called sliver by passing it through a series of rollers, this results in straightening of the individual fibers and making them more parallel to one another.

Open-end Spinning: Open end spinning is a technology for creating yarn without using a spindle.

Ring Spinning: A process of spinning in which the yarn is twisted and drawn while passing through a small metal device traveling rapidly around a ring in the operation of winding the yarn onto a bobbin.

Sheet Dyeing: In continuous sheet dyeing, direct warping beams are used, instead of ball warping logs in the case of Indigo rope dyeing system.

Rope Dyeing Rope dyeing consists of twisting the yarns into a rope that is then quickly dipped into indigo baths. It is considered the best method for dyeing denim as the short dyeing time does not allow the indigo to fully penetrate the fibers, thus creating ring-dyed yarn that fades better and faster than fully dyed yarn

Hand of a Fabric: Fabric hand is the quality of the fabric assessed by the reaction obtained from your sense of touch.

Abbreviations

1RB- Rigid Bi-Blend Fabric 1

1RC- Rigid Cotton Fabric 1

1RT- Rigid Tri-Blend Fabric 1

1WB-Washed Bi-Blend Fabric 1

1WC- Washed Cotton Fabric 1

1WT- Washed Tri-Blend Fabric 1

2RB- Rigid Bi-Blend Fabric 2

2RC- Rigid Cotton Fabric 2

2RT- Rigid Tri-Blend Fabric 2

2WB-Washed Bi-Blend Fabric 2

2WC- Washed Cotton Fabric 2

2WT- Washed Tri-Blend Fabric 2

TB- Tri-Blend

CC- 100% Cotton

BB-Bi-Blend

LB- Rinse

ST-Stone Wash

BT- Hot Bleach Wash

LT- Cold Bleach Wash

EX-High-Speed Extraction Washer

NE- No Extraction Washer

HD- Dryer with Humidity Sensors

AL- Dryer with Algorithm

Purpose

VF Jeanswear has experienced a decline in sales in their North America Market. Fit consistency was identified as one of the key reasons. The purpose of this thesis research was to investigate fit variation in VF Jeanswear denim jeans. The objectives were to (1) assess fit variation in Internal Manufacturing and (2) design a solution to reduce that variation and (3) implement that solution.

In the literature review (Chapter 2), we will see the Lean Six Sigma concepts and basics of the denim manufacturing process which are required to understand the thesis. Chapter 3 includes the case study that uses the DMAIC methodology to achieve improvements. This chapter is divided into five sections.

The first section defines the problem, the scope and the goals of the project. The second section is the measure phase where we have identified important steps, collected the required data, and benchmarked the current performance by defining a performance metric called Range of Fit.

With the help of this information, we revised the problem and mission statement in the define phase. In the fourth section, we analyzed the data by using various tools to explore the underlying root causes of process inefficiency. Based on these findings, we suggested improvements to the process in the fifth section.

In Chapter 4 (Results and Discussions), we see the findings from the experiments performed.

In Chapter 5, we discuss our major findings, conclusions, interpretations of the results and the future projects.

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CHAPTER 2: Literature Review

2.1 Introduction to Denim

Denim jeans are one of the most popular items of clothing worldwide.(McQueen, Batcheller, Moran, Zhang, & Hooper, 2017) The name 'denim' is thought to have originated from the French *serge de Nimes*, a fabric from the town of Nimes in France. It was made of silk and wool, but interestingly denim has always been made of cotton. There was another fabric, a fustian made of cotton, linen and/or wool blend, and the fustian from Genoa, Italy was called jean. By the eighteenth century, jean fabric was made completely of cotton, and used to make men's clothing, valued especially for its property of durability even after many washings. The popularity of denim was also on the rise and it was stronger and more expensive than jean. Even though the two fabrics were very similar in other ways, they did have one major difference: denim was made of one colored yarn and one white yarn while jean fabric was woven with two yarns of the same color (Paul, 2015b).

Denim has had an incredible social and cultural influence on consumers and is considered an expression of youth independence, a symbol of opposition or an attitude towards life, and creates an international appeal of jeans among all age groups. Classic Hollywood movies with rebellious themes starring Marlon Brando and James Dean became symbolic of rebellious youth. Dean and Brando wore blue jeans and leather jackets in the movies, and this clothing style became a symbol of a defiant teen desiring freedom. Originating in the United States, denim fever spread across the world, and the wide acceptance of denim garments everywhere makes it clear that denim is here to stay.(Paul, 2015b)

2.2 History of Denim

George Washington, when President of the US, toured a denim mill in 1789. At that time, denim and jeans were not one apparel item. The partnership of denim and jeans as one apparel idea stems from the inception of Levi Strauss and Co. As its website proclaims: “Levi Strauss and Jacob Davis listened. Jacob was the tailor who in the 1870s first fashioned heavy cotton cloth, thread and metal rivets into sturdy waist overalls for miners seeking durable work pants. Levi in turn met Jacob ‘s needs for patenting and mass production of the product, enthusiastically embracing the idea and bringing it to life. The rest is history: the two created what would become the most popular clothing in the world — blue jeans”(“Chapter 3 Denim and jeanswear : product , markets and the industry,” 2009).

Over the years, Levi Strauss and Co. in the United States, has played a pivotal role in developing denim jeans. The company was founded by Loeb Strauss, who was born in Bavaria, Germany in 1829. Along with his family members, he left Germany in 1847 and sailed to New York, where Loeb’s half-brothers were in business selling wholesale dry goods.

Levi Strauss & Co., founded in 1853, was selling only clothes, boots and other dry goods to small retail stores. In 1873, together with a tailor named Jacob Davis, Levi was granted a patent to manufacture rivets to strengthen workwear made of blue denim. Soon they began manufacturing copper riveted waist overalls out of a brown cotton duck and blue denim, marking the birth of denim jeans. Even though it originated in Europe, the durability and adaptable form of denim found a perfect home in the United States, where soon it became an American icon (Paul, 2015b).

2.3 Denim Jean Manufacturing

2.3.1 Fiber

2.3.1.1 Cotton fiber

Cotton is extensively used in denim, where the fiber quality and staple length are of crucial importance. Denim would not be denim without cotton, but the cultivation of cotton raises sustainability issues due to the quantity of water and pesticides used. The use of organic or naturally colored cotton in denim manufacturing can address the sustainability issues to some extent. Cotton can also be blended with lycra, polyester, lyocell, wool, flax, hemp, and other fibers. for developing special types of denim. These provide a soft and comfortable feel to jeans. Even though many such fibers are now entering the denim sector, it is highly improbable that they will ever replace cotton completely.

(a) (b) (c)

Figure 5(a), 5(b), 5(c): Cotton, Polyester, Spandex("Presidential input support helps farmers double 2017 cotton yield - NewZimbabwe.com," n.d.)

The cotton fiber needs to undergo a series of operations in order to be spun into yarns. Most of the cotton processing techniques for denim manufacture have not changed over the years. Warp and weft are the weaving terms for the directions of the threads that make up a woven fabric. Warp threads are those that run along the length of the yardage and parallel to the selvage whereas, weft threads are the threads that run from selvage to selvage(Fall, n.d.)

Unlike the weft, the production of warp yarn needs special attention, as it can influence the final quality of denim fabric.(Paul, 2015b)

2.3.1 Fabric

The manufacturing process for denim is similar to that of greige fabric up until the weaving stage where Denim Fabric is dyed in the sizing stage, whereas with greige fabric, the dyeing stage depends upon the finished product. Figure 6 provides a high-level summary of the entire denim manufacturing process. Each of these stages will be described in the following sections.

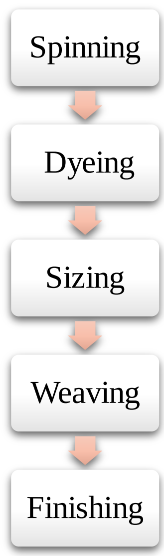


Figure 6: Process Flow Chart of Denim Fabric Manufacturing

2.3.2.1 Spinning

The initial stage of denim production is opening and blending. Opening begins with separating baled cotton fiber into small tufts. The cotton fibers are delivered by air suction from the opening and blending lines, through additional cleaning and blending machines, to the carding machine where they are parallelized and elongated to get durable and resistant yarn. The major functions of carding are to (1) remove foreign matter and short fibers, (2) form the cotton into a web and (3) convert the web into a rope-like form known as a sliver. The drawing process produces a single, uniform sliver from six card slivers. Individual slivers are laid down in the groove of a fast spinning rotor and twisted into yarn. These yarns can be formed by using open-end spinning or ring spinning as we can see in Figure 4.(Paul, 2015a)

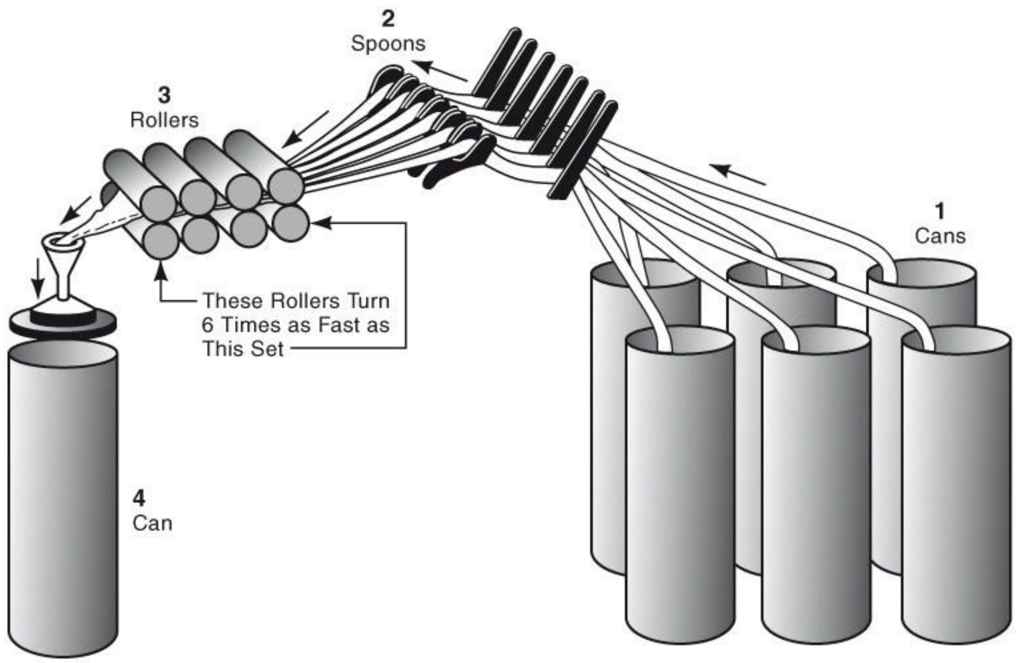


Figure 7: Spinning of Yarn("How Denim Is Made: The Spinning Process," n.d.)

As can be seen in Figure 7, drawing cans (1) feed the slivers to the drawing frame. First, the slivers pass through spoons (2) that guide them and stop the equipment if any break. The rollers (3) turn successively faster, which reduces the size of the slivers and increases their length six-fold. The slivers are combined into one which is deposited into a can (4).

Productivity and yarn quality are getting more important in spinning, and in this respect, rotor spinning is becoming more prominent than the conventional ring spinning. Weaving a combination of ring spun and rotor spun yarns can help to reduce fabric costs while still maintaining some favorable ring spun fabric characteristics.(Paul, 2015b) We can see how spinning looks like in Figure 8.

Figure 8: Spinning of Yarn for Denim Fabric("Essential Denim Knowledge: How Yarn Is Spun," n.d.)

2.3.2.2 Dyeing of Denim

The dyeing for denim fabric happens at the next stage. The two most popular methods of dyeing Denim Fabric are rope dyeing and sheet dyeing (Kiron, 2012?)

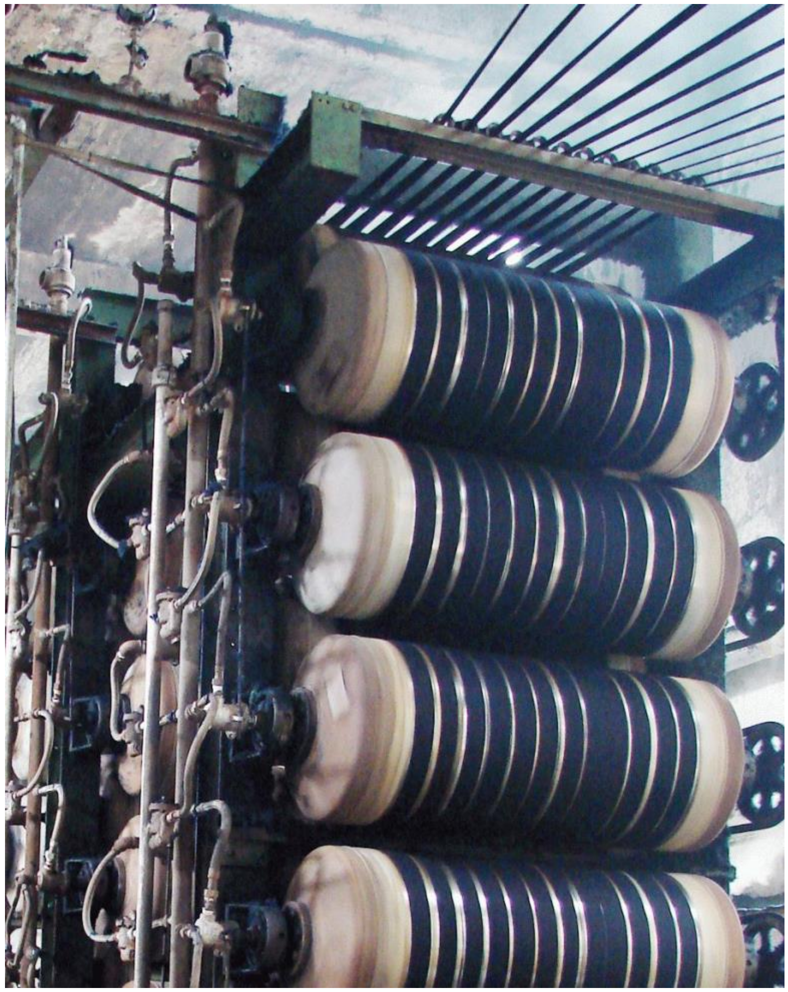
- 

Figure 9: Rope Dyeing of Denim Yarn(“Rope Dyeing - Heddels,” n.d.)

Rope dyeing which we can see in Figure 9, consists of twisting the yarns into a rope that is then quickly dipped into indigo baths. It is considered the best method for dyeing denim as the short dyeing time does not allow the indigo to fully penetrate the fibers, thus creating ring-dyed yarn that fades better and faster than fully dyed yarn.(Chavan, 2015)

2.3.2.3 Sizing

The main purpose of sizing warp yarns is to encapsulate the yarn with a protective coating. This protective coating reduces yarn abrasion during weaving. The size also reduces yarn hairiness, preventing adjacent yarns from becoming entangled. For many years, native or slightly modified starches with corresponding binders were regarded as the most economical size for indigo warps. The change to garment-washed denim led to the development of new sizing recipes. The type and quantity of size used depends on what finishing operations will be used.

2.3.2.4 Weaving

Weaving is the final process in the manufacturing of denim and is very important in determining the quality of the final garment as we can see in Figure 7. Denim fabric is woven as 3/1 twill by the interlacement of indigo dyed warp and greige weft, and the yarn counts influence the fabric properties such as weight, fabric tightness, cover, drape, tensile strength and other properties. The weaving looms often used for denim are projectile, rapier and air jet looms.

Figure 10: Weaving of Denim Fabric(“Denim and Jeans Manufacturing Process,” n.d.)

In general, the denim market is highly competitive and is driven by volume. So, the competitiveness of denim weaving companies depends on aspects like process optimization and their marketing profile. Possible sources of competitive advantage include the use of engineered yarns, weaving denim efficiently in intelligent machines and using online quality control systems. All these could reduce energy consumption in weaving and also optimize material and resource efficiency. The industrial implementation of these technologies represents the future of denim weaving, which should be economically viable and produce high quality denim**.**(Paul, 2015b)

2.3.2.5 Finishing of Fabric

Textile Finishing refers to all the processing operations that are generally applied to the fabrics to improve their appearance, hand of the fabric and other properties. Finishing is also done to textiles based on what application the fabric is used for e.g.: Water repellency finish for Raincoats.(Paul, 2015a) Cotton woven and knitted fabrics are often subjected to washing and we observe significant changes in their dimension. The fabrics get shortened in length and width. This very undesirable phenomenon is known as shrinkage.(Neckář & Das, 2007)

The purpose of Sanforization of denim fabric is to stretch, fix and shrink the denim fabric in length at the mill. This is done in order to reduce the amount of shrinkage that can happen after consumer washes their jeans for the first time. The result of sanforization leads to 1-3% shrinkage, as opposed to up to 10% shrinkage with unsanforized denim.

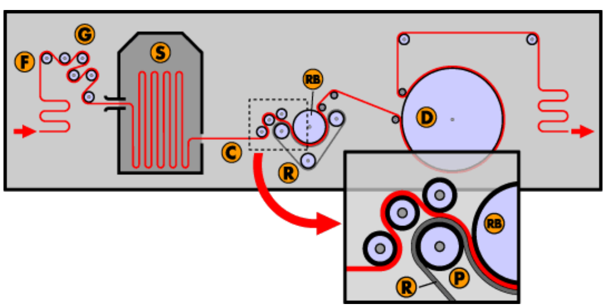


Figure 11: Schematic depiction of the controlled compressive shrinkage process(Neckář & Das, 2007)

Table 1: Abbreviations explained for Sanforization process (Neckář & Das, 2007)

F	Fabric
G	Guide Rolls + Control Rolls
S	Skyer
R	Rubber Belt
C	Clip Expander
P	Pressure Roll
RB	Rubber Belt Cylinder
D	Dyer

A diagram of sanforization can be seen in Figure 11. The process begins as the cloth is fed into the sanforizing machine. It is then fed through the skyer where the cloth is moistened with steam from water. The cloth goes through a heated rotating cylinder, which presses a rubber sleeve against another rotating cylinder, causing the fabric to stretch. As the rubber sleeve continues to compress and expand, it eventually relaxes to its normal thickness and length while bringing the fabric with it, causing it to shrink. Finally, the fabric goes into the dryer where the moisture is removed, and the shrinkage becomes permanent.(Dhouib et al., 2016)

2.3.3 Cutting

The pattern makers who are in the product development team make all the required patterns for sewing of jeans. The patterns change based on three components:

- Sizes
- Styles
- Shrinkage of Fabric

Depending on these factors multiple patterns are made on AutoCAD. AutoCAD is a computer-aided design (CAD) program used for 2-D and 3-D design and drafting. It is used in pattern making, architecture, construction, and manufacturing to assist in the preparation of blueprints and other engineering plans(Greenlee, n.d.) The pattern cut for Denim jeans is shown in Figure 12.

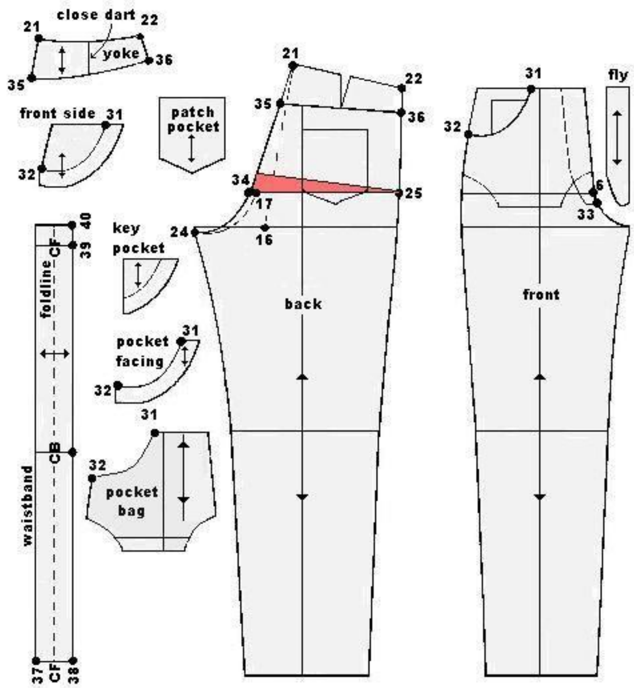


Figure 12: Pattern Cut for Jeans("CLASSIC JEANS | Weekend designer," n.d.)

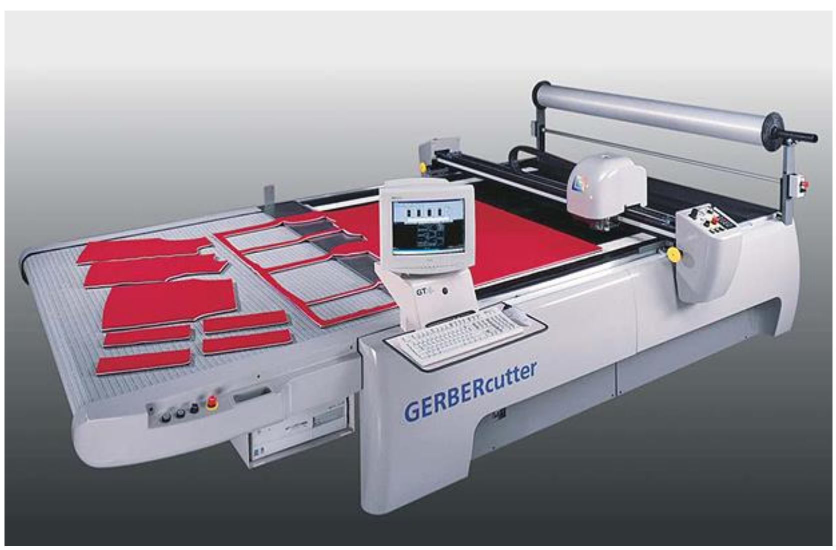


Figure 13: Gerber Cutter Machine("China Gerber Cutter," n.d.)

These patterns are then fed into the Gerber machine, which is shown in Figure 13, at the finishing facility in the manufacturing plants. Here the Gerber machine performs the following steps:

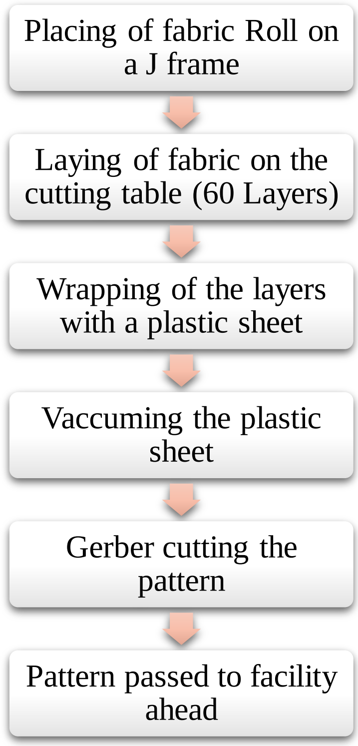


Figure 14: Process flow for Gerber Cutter Machine

2.3.4 Sewing

Good sewability implies better ease of converting fabric into garments. In garment industries, high-speed sewing is a quite complex process, involving many preparations for the perfect seam quality.(Chaudhary, Sikka & Bansal, 2016)

The stitching process gives birth to denim jeans, and the joining techniques are crucial in determining shape, fitting and style. The conversion of denim fabric into garments requires machines that are able to cope with the density of the fabric and the thickness of the seams. Therefore, heavy duty machines need to be used and specialized components have been developed to feed the material effectively through the machine. Other components such as heavy-duty needles, sewing threads that have high strength for securing the seams, and buttons and studs for securing the pockets have been specially developed for this garment.

Figure 15: Sewing of Denim(“Denim Jean Workshop | UAL,” n.d.)

Challenges exist in joining including stress on the operators when stitching the material due to its heavy weight and dense construction. This can create greater operator fatigue. Sophisticated equipment to automate certain processes have been developed to reduce some of this fatigue and at the same time increase productivity. Future trends in the joining of denim will be dictated by the developments in the material itself, environmental drivers and, of course, economic factors. The possible use of laser welding or soluble sewing threads that can be easily removed from a garment will allow for easier reconstruction of jeans into a new product.(Paul, 2015b)

The seam parameters such as seam strength, elasticity, durability, puckering, appearance and needle cut/yarn severance are influenced by fiber types such as cotton, polyester, modal, bamboo and their blend ratio.(Choudhary, Sikka, & Bansal, 2018)

2.3.5 Industrial washing of denim

Denim is actually a stiff and dull blue fabric without any fashion appeal, and washing is the revolutionary process that has changed this mundane image of denim. Denim garment washing is now an indispensable process for producing fashion items for leisure wear. (Paul, 2015b) Industrial washing is one of the finishing methods applied to fabric or garment, which together with the use of new technologies and equipment produces a desired result. For finishing of denim fabrics, a range of treatment methods is used, namely mill wash or rinse wash, stonewash, moon wash, sand wash, bleach, overdyed-look, damaged-look, and scrubbed-look(Id, Nrc, & Library, 2006) They all are aimed at creating a new fabric appearance.

2.3.5.1 Types of Denim Washing

In contrast to the methods of finishing fabrics, different types of washing have been used on completely sewn Denim readymade garments to give a distressed Denim look or a startling finished garment. Two of these wash types are stone-washing and enzyme washing.

In stone-washing, the Denim garment is washed along with pumice stone in industrial washing machines. Denim is a stiff fabric made basically of cotton where the warp yarns are dyed with indigo that remain on the fabric surface. During washing the warp yarns are spun together in the washing machine producing a lighter color on the garment and creating better contrasts for a distressed look. To minimize unwanted wear and tear of the garment, the temperature, amount of pumice stone, and wash time have to be set carefully and controlled in the washing process. The washing of denim with pumice stone alone could cause wear and tear of the garment and would be time consuming.(Khan & Mondal, 2012)

2.3.5.1.1 Enzyme washing

Enzyme washing can be used to replace or complement the stone washing process. The ecological aspects of denim garment washing are now becoming increasingly important and enzymes have contributed to the improved environmental profile of this process. The application of cellulase enzymes is well known to the majority of industrial laundries. Big brands and retailers are also very much aware of their sustainability aspects. Laccase enzymes can be used as an alternative to chemical bleaching where the enzyme oxidizes indigo and decomposes it.(Paul, 2015b)

2.3.6 Finishing

Finishing of denim fabrics and jeans can provide aesthetic as well as functional properties. There are countless dry and wet processes in denim garment processing to achieve fading, excellent fabric feel and unique looks. Apart from such processes for achieving special fashion effects, several functional finishes can also be applied to denim garments for providing technical and functional properties. Microencapsulation, plasma techniques and nanotechnology are offering different possibilities that were not possible to achieve with normal finishing chemicals.

The functional finishes can create anti cellulite, odor resistant, wrinkle free, water/ oil repellent mosquito repellent, antimicrobial, UV protection and flame-retardant properties on denim garments. Thus denim, which is well recognized in the casual wear sector, is now finding new markets in technical textiles and non-apparel applications. More interestingly, many fashionable and multifunctional effects can be simultaneously created on denim garments.(Paul, 2015b)

2.4 Denim Shrinkage

Nowadays, blue jeans garments constitute one of the most important products of manufactured fabrics. Many treatments are applied to give them attractive and fashionable effects. Indeed, one of the biggest quandaries of the garment's finishing is the unpredictable, uncontrollable shrinkage of the clothes due to the huge variety of fashion treatments (Dhouib et al., 2016).

The types of assembling and finishing treatment processes are usually associated with uncontrolled cloth shrinkage, which limits the finishers in attaining cloth shades and cloth effects requested by customers. Moreover, the reproducibility of the same finishing effects is very difficult with the current methods followed by different manufacturers.(Khedher, Dhouib, & Sakli, 2013)

2.5 Changes in denim

Stretch denim has gained an increasing market share in recent years because of global demand.(Kan & Yuen, 2009) Woven garments stretch mainly along one direction and are not very elastic, unless they are woven from stretchable material such as spandex(Choudhary et al., 2018) Over the past decade, elastic yarns and fabrics have been used more and more around the world because of their characteristics of wear, comfort and functionality. As a result, many studies have investigated the spinning and weaving of elastic textile structure. (El-Ghezal, Babay, Dhouib, & Cheikhrouhou, 2009) Although dimensional instability and distortion after home laundering are perceived by customers to occur mostly in knitted goods rather than woven cotton fabrics, these problems do still occur in stretchable woven fabrics (Kan & Yuen, 2009)

2.6 Concept of Fit for VF

With increasing awareness about fit amongst consumers and the variety of new fabrics and products in the market, maintaining the fit of a garment has become a big concern for companies. For denim jeans, fit is the most important parameter. As ease of online shopping has driven consumers out of the brick and mortar stores and they do not get to try their clothes online, having a very precise size chart and keeping the production consistent with it has become very important. These were the same issues that caused VF Jeanswear to start closely focusing on fit consistency. They go through a long process to minimize the measurement defects in the finished cloth. Unfortunately, in many cases, their tests indicate they are not meeting their specified measurements (Dhouib et al., 2016)**.**

Fit of denim jeans in VF depends on these 5 components:

- Waist of the jeans
- Thigh measurement

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- Inseam length
- Seat size
- Back rise

With the increasing number of fabrics, fit and styles, VF is currently having issues with the consistency in their fit for denim. The data collected from online reviews and instore reviews indicate that the major customer complaints are that the jeans are too big or too small at the waist for their usual size. Along with this, customers also complain about the jeans having irregular inseam length between the same sizes.

CHAPTER 3: Methodology

VF Jeanswear has experienced a decline in sales in their North America Market. Fit consistency was identified as one of the key reasons. The purpose of this thesis research was to investigate fit variation in VF Jeanswear denim jeans. The objectives were to (1) assess fit variation in Internal Manufacturing and (2) design a solution to reduce that variation and (3) implement that solution. Internal Manufacturing consists of the VF manufacturing facilities present in North America and Central America. The data were collected and analyzed using the Lean Six Sigma methodology. Lean Six Sigma consists of five stages: Define, Measure, Analyze, Improve and Control. Each stage will be described in the following sections.

3.1 Define:

Define is the first phase of DMAIC methodology. The goals of the Define phase are to define the

- Main business problem
- Mission or the goal of the project
- Team

The project was launched with a kick-off meeting in the Greensboro office of VF Corporation. The people at the meeting included the VP of Operations Excellence, Senior Director of Quality Assurance and Quality Assurance Manager. The purpose of the kick-off meeting was to define the business problem and establish a mutual understanding of the project's guidelines.

3.1.1 Problem and Mission Statement

After the kick off meeting I had a better understanding of the problem and articulated a preliminary problem and mission statement

Problem Statement: VF *Jeanswear denim jeans show large deviations from the specification limits for the waist and inseam. (The team believed this contributed to a loss in sales.)*

Mission Statement: *The purpose of the current study was to reduce the fit variation in the waist and inseam. The current study investigated how to bring the waist and inseam back in spec. The link to loss in sales was beyond the scope of this study.*

By the end of the Define phase, the team had defined the problem, stated the mission, and scoped the project to make it manageable and focused.

3.2 Measure:

After the identification of the problem the project moved forward with the measure phase. In this phase all the factors and processes which were related to the problem were identified.

The Senior Director of Quality Assurance provided the company's Audit Data from January 2018-July 2018. The data from these 7 months were analyzed to understand the current manufacturing process and fit variation.

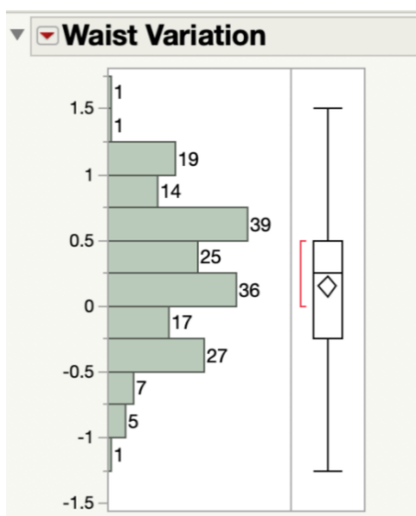


Figure 16: Waist Variation Distribution for Men's Sizes 32*32

Table 2: Summary Statistics for Men's Waist Variation

Summary Statistics	Male 32*32 Waist
Mean	0.15"
Std Dev	0.54"
Range of fit (99% CI)	3.24"
Range of fit (95% CI)	2.16"

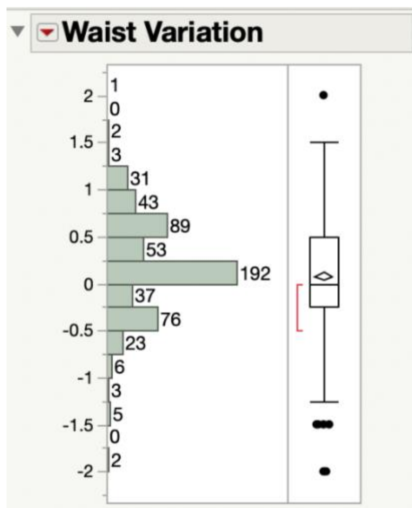


Figure 17: Waist Variation Distribution for Women's Sizes 10 and 12

Table 3: **Summary Statistics for Women's Waist Variation**

Summary Statistics	Female sizes 10 and 12 Waist
Mean	0.07"
Std Dev	0.52"
Range of fit (99% CI)	3.12"
Range of fit (95% CI)	2.08"

Figure 16 and Table 2, Figure 17 and Table 3 shows the summary of the measured data for Men's sizes 32*32 waist and Women's sizes 10 and 12 waist respectively.

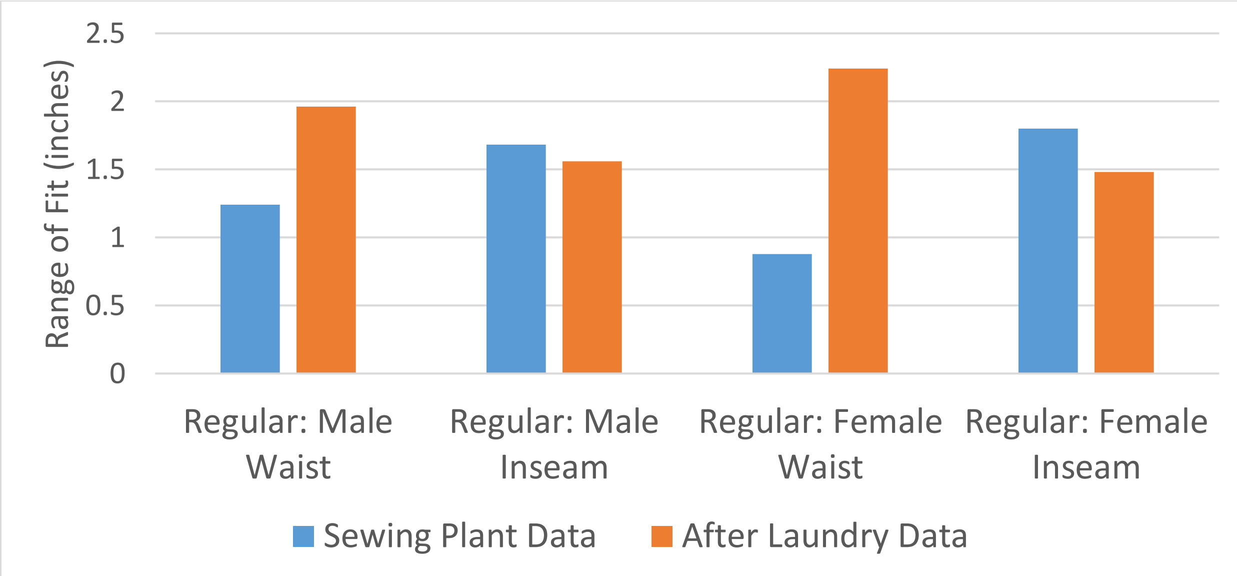


Figure 18: Range of Fit (95% CI) of Sewing and Finishing Audit Data 100% Cotton Denim

Figure 19: Range of Fit (95% CI) of Sewing and Finishing Audit Data Stretch Denim

Figure 18 and Figure 19 shows the fit range that comes out of sewing plant and finishing plant for 100% cotton and stretch denim respectively.From these Graphs we can see that sewing plants are less than 0.5” over the tolerance for sewing i.e: (-0.5”,+0.5”), whereas the finishing plants or after laundry data is 1” abover the tolarence i.e: (-0.75”, +0.75”).This helps us understand that majority of the out of tolerance data were from laundry. Thus the scope of the study became the process in the Finishing Facility.

VF Jeanswear has manufacturing plants in Asia and Africa in addition to North America. Data were collected and analyzed from those plants to assess their variation, in hopes they were performing better with their fit so we could study what they were doing.

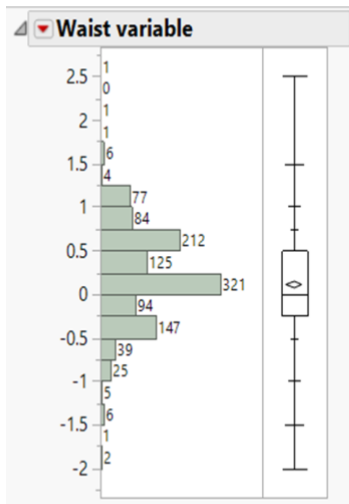


Figure 20: Waist Variation distribution for the Entire Data Set

Table 4: Summary Statistics for Waist Variation of Entire Data Set

Summary Statistics	Entire Data Set Variation
Mean	0.11”
Std Dev	0.58”
Range of fit (99% CI)	3.48”
Range of fit (95% CI)	2.13”

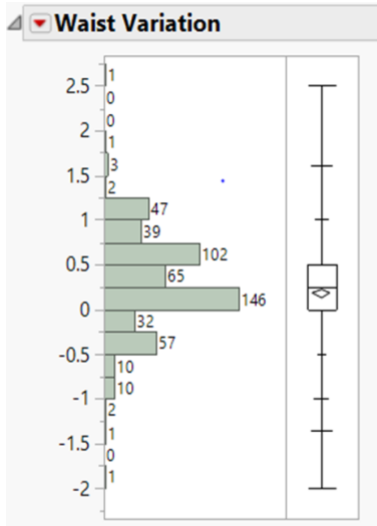


Figure 21: Waist Variation distribution for the Internal Manufacturing

Table 5: Summary Statistics for Waist Variation of Internal Manufacturing

Summary Statistics	Internal Manufacturing
Mean	0.18”
Std Dev	0.52”
Range of fit (99% CI)	3.13”
Range of fit (95% CI)	2.08”

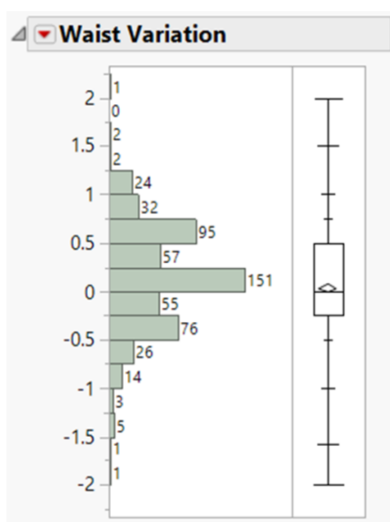


Figure 22: Waist Variation distribution for the Asia and Africa

Table 6: Summary Statistics for Waist Variation of Asia and Africa

Summary Statistics	Internal Manufacturing
Mean	0.03”
Std Dev	0.53”
Range of fit (99% CI)	3.19”
Range of fit (95% CI)	2.13”

Based on the analyses shown in Figures 20, 21 and 22 and Tables 4,5 and 6, it did not appear that Asia and Africa showed a significantly better performance. Therefore, the scope of the current study remained North America. VF may study Asia and Africa in the future.

3.2.1 Process steps

After analyzing the fit variation to determine the size of the problem, a map of the manufacturing process was created. I personally observed the process at the finishing and sewing facility of VF Jeanswear in Mexico. The process map was used to determine potential points in the process that could be causing variation. Figure 23 is a high-level process map.

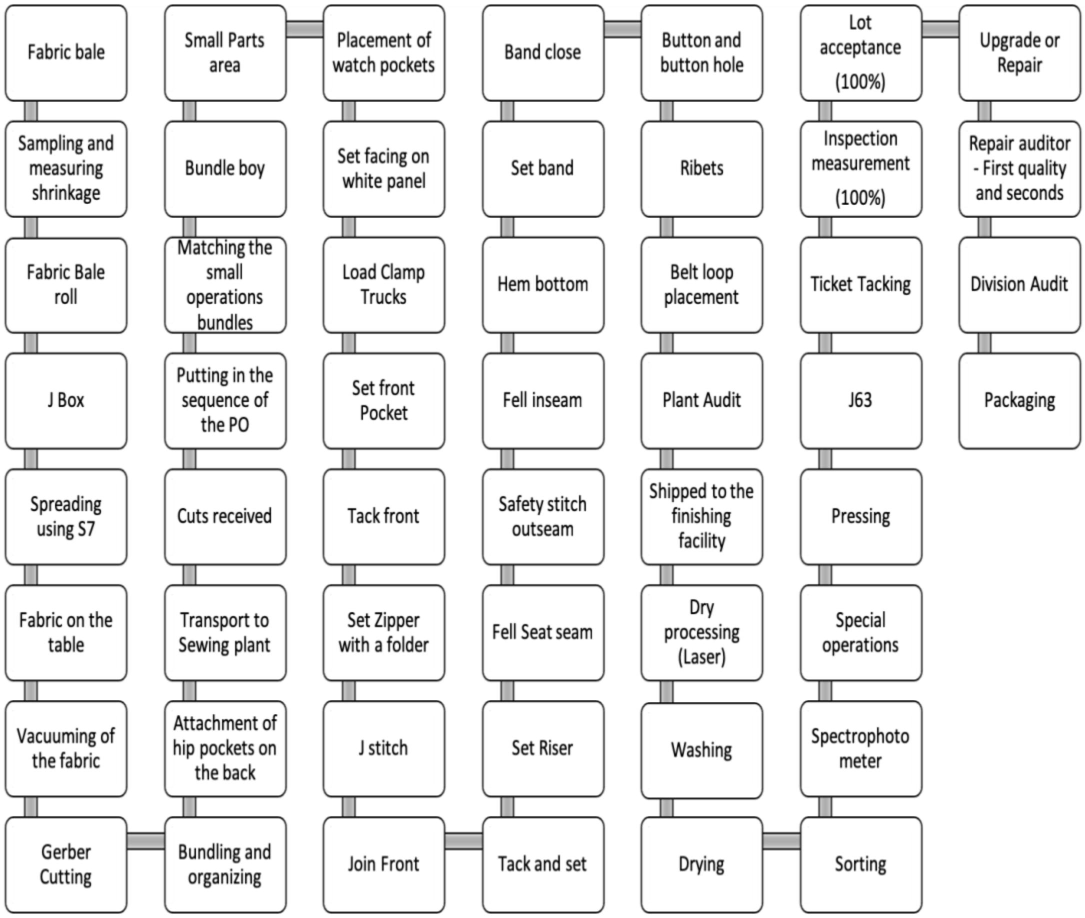


Figure 23: Process Flow Chart of Denim Manufacturing

After understanding the current fit variation and the manufacturing process, we refined the problem statement.

Problem Statement: VF *Jeanswear denim jeans showed the range of fit for Men's Waist as 3.24" and showed the range of fit for Women's Waist as 3.12". (The team believed this contributed to a loss in sales.)*

Mission Statement: *The purpose of this study was to reduce the range in waist variation by 0.5" by April 2019. (The team believed this would result in increased sales.)*

3.3 Analyze

The purpose of the Analyze phase is to get to the root cause of the problem, using tools such as brainstorming and experiments, so it can be addressed.

The first step was to brainstorm areas where the variation in waist and inseam could occur. The process map was key in this process. Figure 24 shows the cause and effect diagram summarizing the areas. In Figure 25, the highlighted squares correspond to places in the process identified as having the highest variation.

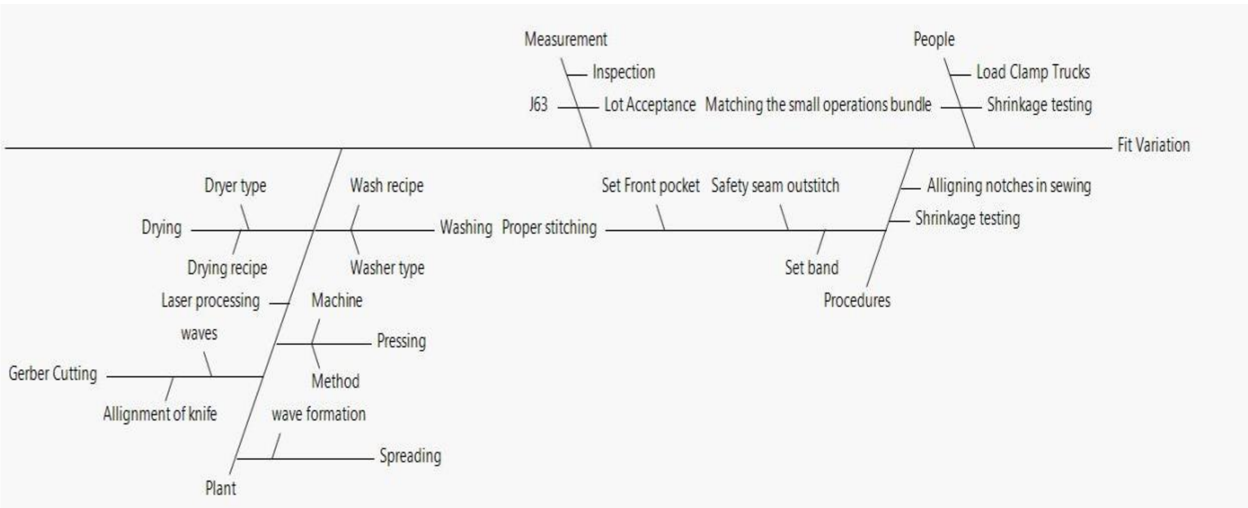


Figure 24: Cause and effect diagram

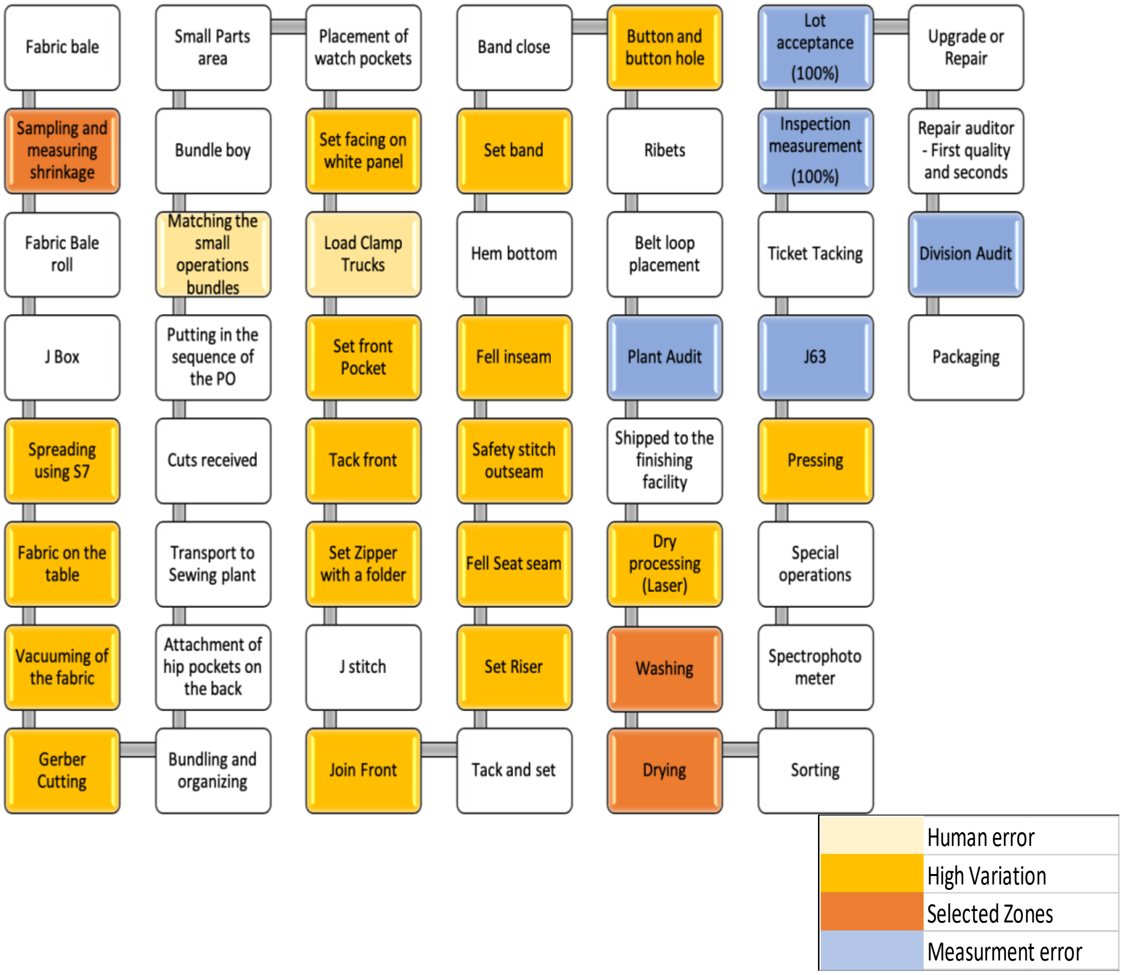


Figure 25: Highlighted Process Flow Chart of Denim Manufacturing

From the flow chart in Figure 25 we can see that there are multiple areas where variation could occur. For the purpose of the thesis study, Laundry and Pressing were studied. The other areas were set aside for future study.

Upon completion of the Measure phase, the plan of attack created was:

Plan of Attack

- Gage R&R Study
- DOE
    - Screening
    - Different Purchase order number

- Product Development Laundry vs Industrial Washers and Dryers
- Different Dryer Temperatures

3.3.1 Gage R&R Study

A gage repeatability and reproducibility (R&R) study is used to assess a measurement system's ''capability'' by determining how much of the observed variability in any of these applications can be attributed to the gauge, as well as how large the components of the measurement variation are. Two such components are repeatability and reproducibility, where repeatability refers to the measurement variation under fixed conditions and reproducibility typically refers to operator-to-operator variation.(Weaver, Hamada, Vardeman, & Wilson, 2012)
I performed a Gage R&R study in the manufacturing facility on the measurement metric of Shrinkage. The measurement system had to be evaluated to ensure the validity and accuracy of the data collected.

3.3.1.1 Measurement System

Currently the shrinkage for the denim fabric is measured in the facility by cutting the fabric into swatches of 18 x 18 inches squares and are marked accordingly. These fabric swatches undergo washing based on different wash codes and fabric types. After washing and drying, the fabric swatches are conditioned at 65% RH and 20 °C for at least 24 hours.

After the conditioning period, linear shrinkage in both warp and weft directions are measured by using a shrinkage % ruler. These measurements are taken from the previous 18 x 18 inches marking on the fabric swatches.

The fabric swatches can be seen in the Figure 26.

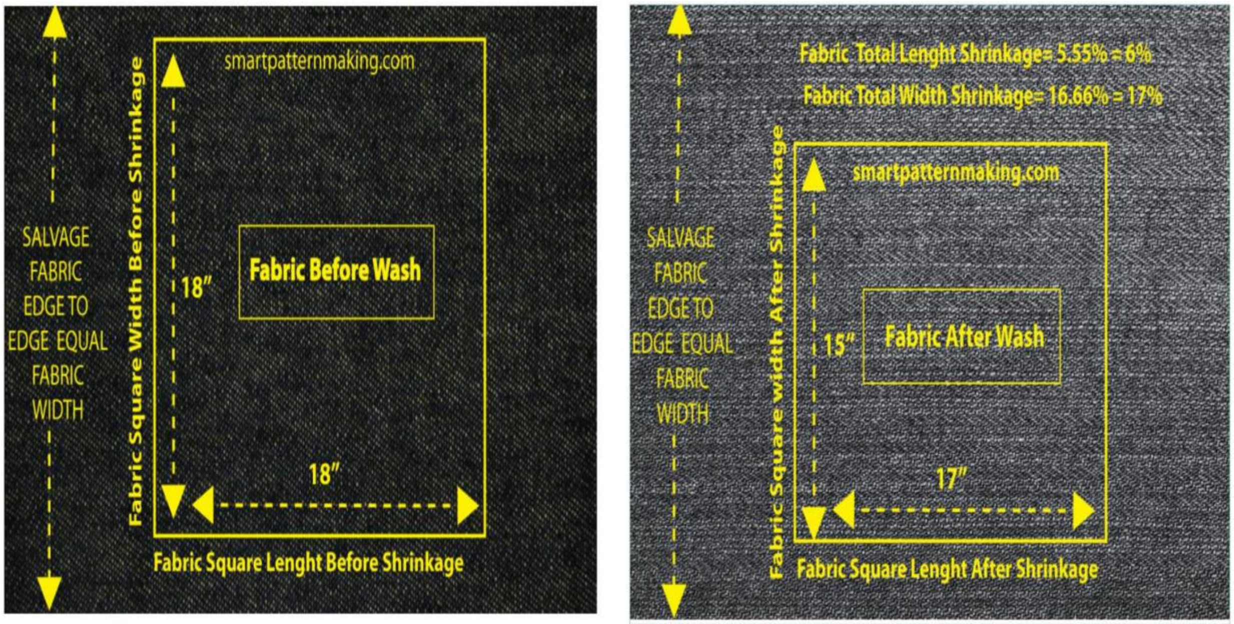


Figure 26: Shrinkage Testing Method

3.3.1.2 Design of Study:

For the Gage R&R study of shrinkage, 12 fabric swatches and 3 different types of fabric Cotton, Bi-Blend (Cotton + Polyester) & Tri-Blend (Cotton + Polyester + Spandex), of which 2 rigid (just marked and not washed) and 2 washed fabrics for each fabric type were used.

In summary, the fabrics used were

- 2 Rigid Cotton
- 2 Washed Cotton
- 2 Rigid Bi-Blend
- 2 Washed Bi-Blend
- 2 Rigid Tri-Blend
- 2 Washed Tri-Blend

Further 3 operators who currently measure the shrinkage in the facility were included.

Each Fabric swatch was measured three times. The swatches were measured in random order. Each Fabric swatch was measured twice.

Finally, the measurements were made on Fill Shrinkage and Warp Shrinkage and the following calculations were made:

Total Measurements: Fill Measurements + Warp Measurements

Number of fill Measurements

*= (Number of Fabrics) *(Number of Operators) *(Number of times each fabric is measured)*

*= **(12) * (3) * (2) * (3)***

= 108 measurements

Number of warp Measurements

*= (Number of Fabrics) *(Number of Operators) *(Number of times each fabric is measured)*

*= **(12) * (3) * (2) * (3)***

= 108 measurements

3.3.1.3 Data Collection

After the Gage R&R study was designed, the operators were asked to measure the fabric swatches using their usual method and data were recorded in an excel data sheet.

Table 7 shows the data for one of the operators.

Table 7: Operator 1's Data for Gage R&R Experiment

Operator	**Fabric Swatch**	**Warp Shrinkage %**	**Fill Shrinkage %**
Rosario	1RC	0	0
Rosario	2WB	-4	-14.7
Rosario	1WB	-3.9	-15
Rosario	2RB	0	-0.1
Rosario	1WB	-3.9	-15
Rosario	1WC	-3.3	-3.1
Rosario	1RC	-0.1	0
Rosario	2RT	0	-0.2
Rosario	1RB	0	-0.1
Rosario	1WC	-3.3	-3.1
Rosario	2WB	-4.1	-14.7

Table 7 (Continued)

Rosario	1RC	0	-0.1
Rosario	2RC	0	0
Rosario	2RB	0	-0.1
Rosario	1WT	-2.8	-15.4
Rosario	1RB	0	0
Rosario	1WT	-2.8	-15.9
Rosario	2WC	-2.6	-2.1
Rosario	2WB	-4	-14.8
Rosario	2RC	0	0
Rosario	2RB	0	-0.1
Rosario	2WT	-5.1	-17.1
Rosario	1WT	-2.8	-15.8
Rosario	2RT	0	-0.1
Rosario	1RT	0	-0.2
Rosario	1WB	-3.9	-15.1
Rosario	1RT	0	-0.1
Rosario	2WT	-5.1	-17
Rosario	1RB	0	0
Rosario	2RT	0	-0.2
Rosario	1WC	-3.4	-3
Rosario	2WC	-2.5	-2.4
Rosario	2RC	0	0
Rosario	1RT	0	-0.2
Rosario	2WT	-5.1	-17
Rosario	2WC	-2.6	-2.4

This was repeated for the two other operators.

The fabrics swatches were marked with short names for identification. These are analyzed further in the results chapter

3.3.2 Screening Design of Experiment

Screening experiments are conducted when a large number of factors are to be studied but there is limited time and resources. Therefore only a few runs can be conducted. These experiments are performed for identification of the dominant factors. (Mason, Gunst, & Hess, n.d.)

3.3.2.1 Designing of Experiment

As we saw from the process flow chart and brainstorming, Laundry created some of the highest variation. Therefore, the screening experiment was conducted in the Laundry section.

The factors and levels used in the experiment were:

Factor 1: Fabric type- 3 Levels

- 100% Cotton
- Bi-Blend
- Tri-Blend

Factor 2: Wash Type-4 Levels

- Rinse
- Stone Wash
- Hot Bleach
- Cold Bleach

Factor 3: Washer Type- 2 Levels

- High Speed Extraction Washer
- No Extraction Washer

Factor 4: Dryer Type- 2 Levels

- Dryer with Humidity Sensor Mechanism
- Dryer with Algorithm Mechanism

After the factors and levels were decided, the experiment was designed using the DOE platform in JMP Pro Version 14.

Number of runs

*= (Fabric Type) * (Wash Type) * (Washer Type) * (Dryer Type)*

*= (3) *(4) *(2) *(2)*

=48 runs

Table 8: DOE For Screening Experiment

Factor	Fabric Type	Wash type	Washer type	Dryer Type
Run number				
1	Cotton	Rinse	High Speed Extraction	Humidifier
2	Cotton	Rinse	High Speed Extraction	Algorithm
3	Cotton	Rinse	No Extraction	Humidifier
4	Cotton	Rinse	No Extraction	Algorithm
5	Cotton	Stone Wash	High Speed Extraction	Humidifier
6	Cotton	Stone Wash	High Speed Extraction	Algorithm
7	Cotton	Stone Wash	No Extraction	Humidifier
8	Cotton	Stone Wash	No Extraction	Algorithm
9	Cotton	Cold Bleach	High Speed Extraction	Humidifier
10	Cotton	Cold Bleach	High Speed Extraction	Algorithm
11	Cotton	Cold Bleach	No Extraction	Humidifier
12	Cotton	Cold Bleach	No Extraction	Algorithm
13	Cotton	Hot Bleach	High Speed Extraction	Humidifier
14	Cotton	Hot Bleach	High Speed Extraction	Algorithm
15	Cotton	Hot Bleach	No Extraction	Humidifier
16	Cotton	Hot Bleach	No Extraction	Algorithm
17	Bi-Blend	Rinse	High Speed Extraction	Humidifier
18	Bi-Blend	Rinse	High Speed Extraction	Algorithm
19	Bi-Blend	Rinse	No Extraction	Humidifier
20	Bi-Blend	Rinse	No Extraction	Algorithm
21	Bi-Blend	Stone Wash	High Speed Extraction	Humidifier
22	Bi-Blend	Stone Wash	High Speed Extraction	Algorithm
23	Bi-Blend	Stone Wash	No Extraction	Humidifier
24	Bi-Blend	Stone Wash	No Extraction	Algorithm
25	Bi-Blend	Cold Bleach	High Speed Extraction	Humidifier
26	Bi-Blend	Cold Bleach	High Speed Extraction	Algorithm
27	Bi-Blend	Cold Bleach	No Extraction	Humidifier
28	Bi-Blend	Cold Bleach	No Extraction	Algorithm
29	Bi-Blend	Hot Bleach	High Speed Extraction	Humidifier
30	Bi-Blend	Hot Bleach	High Speed Extraction	Algorithm
31	Bi-Blend	Hot Bleach	No Extraction	Humidifier

Table 8 (Continued)

32	Bi-Blend	Hot Bleach	No Extraction	Algorithm
33	Tri-Blend	Rinse	High Speed Extraction	Humidifier
34	Tri-Blend	Rinse	High Speed Extraction	Algorithm
35	Tri-Blend	Rinse	No Extraction	Humidifier
36	Tri-Blend	Rinse	No Extraction	Algorithm
37	Tri-Blend	Stone Wash	High Speed Extraction	Humidifier
38	Tri-Blend	Stone Wash	High Speed Extraction	Algorithm
39	Tri-Blend	Stone Wash	No Extraction	Humidifier
40	Tri-Blend	Stone Wash	No Extraction	Algorithm
41	Tri-Blend	Cold Bleach	High Speed Extraction	Humidifier
42	Tri-Blend	Cold Bleach	High Speed Extraction	Algorithm
43	Tri-Blend	Cold Bleach	No Extraction	Humidifier
44	Tri-Blend	Cold Bleach	No Extraction	Algorithm
45	Tri-Blend	Hot Bleach	High Speed Extraction	Humidifier
46	Tri-Blend	Hot Bleach	High Speed Extraction	Algorithm
47	Tri-Blend	Hot Bleach	No Extraction	Humidifier
48	Tri-Blend	Hot Bleach	No Extraction	Algorithm

In Table 8 we can see the DOE for the Full Factorial ANOVA experiment. There is a total of 96 runs including pseudo replications.

3.3.2.2 Performing of Experiment & Data Collection

After the experiment was generated, fabric swatches were cut for each run and coded. This can be seen in Figure 27.

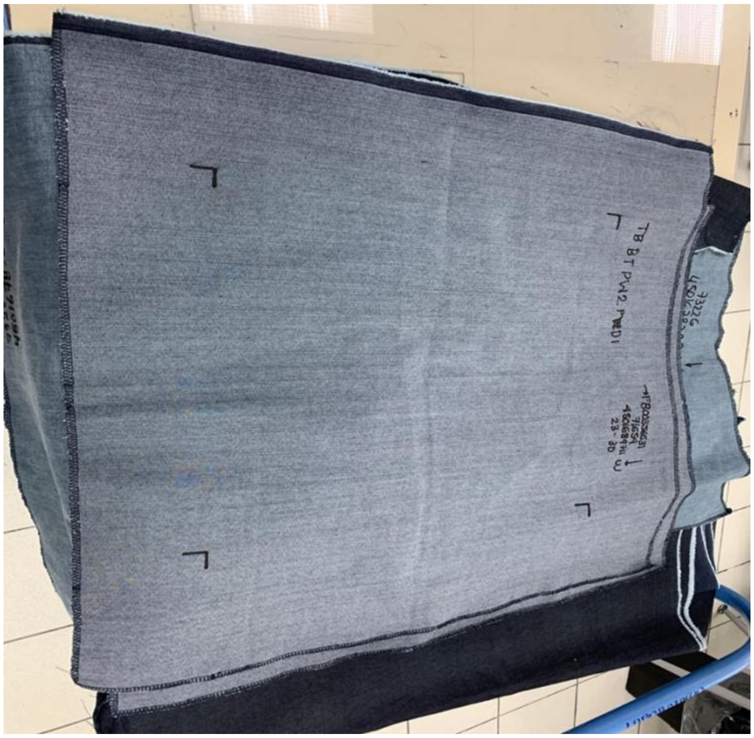


Figure 27: Image of Various Fabric Swatches

The runs were performed in the laundry section of the VF Jean Manufacturing plant in Merida, Yucatan. A total of 4 Measurements were taken for each run (% of shrinkage)

- After wash fill
- After wash warp
- After dry fill
- After dry warp

The operators who were used in the Gage R&R were asked to measure all fabric swatches.

Figure 28: Image of Shrinkage Measurement of Fabric Swatches

A data collection sheet was created, and the measurements recorded.

3.3.3 Different Purchase Order numbers

We wanted to understand how different PO numbers of the same fabric code could have different variation and how that can affect the overall fit. Based on the results of the experiment, 100% cotton fabric did not show a lot of variation and it remained consistent throughout the washes. Therefore, only Bi-Blend and Tri-Blends used in further experimentation.

3.3.3.1 Designing of Experiment

For the experiment on different PO numbers, three factors were used.

The factors and levels were:

Factor 1: Fabric Type- 2 Levels

- Bi-Blend Fabric

- Tri-Blend Fabric

Factor 2: Wash Type: 3 Levels

- Rinse
- Hot Bleach
- Cold Bleach

Factor 3: PO- 5 Levels

- PO 1
- PO 2
- PO 3
- PO 4
- PO 5

The number of runs to be made were calculated using the following formula. The designs were generated using JMP PRO 14.

Number of runs

*= (Fabric Type) * (Wash Type) * (PO number)*

*= (2) *(3) *(5)*

= 30

Table 9: DOE of Different PO number Experiment

Factor	Fabric Type	Wash type	PO Number
Run number			
1	Bi-Blend	Rinse	PO 1
2	Bi-Blend	Rinse	PO 2
3	Bi-Blend	Rinse	PO 3
4	Bi-Blend	Rinse	PO 4
5	Bi-Blend	Rinse	PO 5

Table 9 (Continued)

6	Bi-Blend	Hot Bleach	PO 1
7	Bi-Blend	Hot Bleach	PO 2
8	Bi-Blend	Hot Bleach	PO 3
9	Bi-Blend	Hot Bleach	PO 4
10	Bi-Blend	Hot Bleach	PO 5
11	Bi-Blend	Cold Bleach	PO 1
12	Bi-Blend	Cold Bleach	PO 2
13	Bi-Blend	Cold Bleach	PO 3
14	Bi-Blend	Cold Bleach	PO 4
15	Bi-Blend	Cold Bleach	PO 5
16	Tri-Blend	Rinse	PO 1
17	Tri-Blend	Rinse	PO 2
18	Tri-Blend	Rinse	PO 3
19	Tri-Blend	Rinse	PO 4
20	Tri-Blend	Rinse	PO 5
21	Tri-Blend	Hot Bleach	PO 1
22	Tri-Blend	Hot Bleach	PO 2
23	Tri-Blend	Hot Bleach	PO 3
24	Tri-Blend	Hot Bleach	PO 4
25	Tri-Blend	Hot Bleach	PO 5
26	Tri-Blend	Cold Bleach	PO 1
27	Tri-Blend	Cold Bleach	PO 2
28	Tri-Blend	Cold Bleach	PO 3
29	Tri-Blend	Cold Bleach	PO 4
30	Tri-Blend	Cold Bleach	PO 5

In Table 9 we can see the DOE chart for different Purchase order Experiment, and it has a total of 30 runs.

3.3.3.2 Performing of Experiment & Data Collection

After the design was generated, fabric swatches were cut for each run and coded.

The runs were performed in the laundry section of the VF Jean Manufacturing plant in Merida, Yucatan. 2 Measurements were taken for each run (% shrinkage)

- After dry fill

- After dry warp

The operators who were did the measuring in the Gage R&R were asked to measure all fabric swatches. A data collection sheet was created, and the measurements recorded.

3.3.4 Different Dryer Temperatures

From the results we could see that the dryer caused the highest amount of shrinkage. Therefore, we experimented to see if there were differences when the dryer temperature was 160° F or 140° F or the current process temperature of 180° F.

3.3.4.1 Designing of Experiment

For the dryer experiment, the factors and levels were:

Factor 1: Fabric Type- 2 Levels

- Bi-Blend Fabric
- Tri-Blend Fabric

Factor 3: Dryer Temperature- 3 Levels

- 140° F
- 160° F
- 180° F

The DOE was designed using JMP.

Number of runs

*= (Fabric Type) * (Dryer Temperature) * (Fabric Replications)*

*= (2) *(3) * (5)*

= 30

Table 10: DOE of Different Dryer Temperatures Experiment

Factor	Fabric Type	Fabric Number	Dryer Temperature
Run number			
1	Bi-Blend	Fabric 1	140°F
2	Bi-Blend	Fabric 1	160°F
3	Bi-Blend	Fabric 1	180°F
4	Bi-Blend	Fabric 2	140°F
5	Bi-Blend	Fabric 2	160°F
6	Bi-Blend	Fabric 2	180°F
7	Bi-Blend	Fabric 3	140°F
8	Bi-Blend	Fabric 3	160°F
9	Bi-Blend	Fabric 3	180°F
10	Bi-Blend	Fabric 4	140°F
11	Bi-Blend	Fabric 4	160°F
12	Bi-Blend	Fabric 4	180°F
13	Bi-Blend	Fabric 5	140°F
14	Bi-Blend	Fabric 5	160°F
15	Bi-Blend	Fabric 5	180°F
16	Tri-Blend	Fabric 1	140°F
17	Tri-Blend	Fabric 1	160°F
18	Tri-Blend	Fabric 1	180°F
19	Tri-Blend	Fabric 2	140°F
20	Tri-Blend	Fabric 2	160°F
21	Tri-Blend	Fabric 2	180°F
22	Tri-Blend	Fabric 3	140°F
23	Tri-Blend	Fabric 3	160°F
24	Tri-Blend	Fabric 3	180°F
25	Tri-Blend	Fabric 4	140°F
26	Tri-Blend	Fabric 4	160°F
27	Tri-Blend	Fabric 4	180°F
28	Tri-Blend	Fabric 5	140°F
29	Tri-Blend	Fabric 5	160°F
30	Tri-Blend	Fabric 5	180°F

In Table 10 we can see the DOE for different dryer temperatures experiment. There are total 30 runs.

3.3.4.2 Performing of Experiment & Data Collection

After the design of experiment was completed, fabric swatches were cut and coded

The runs were performed in the laundry section of the VF Jean Manufacturing plant in Merida, Yucatan. 2 Measurements were taken for each run (% Shrinkage)

- After dry fill
- After dry warp

A data collection sheet was created, and the measurements recorded

3.3.5 PDL & Industrial Washers and Dryers Comparison

PDL (Product Development Laundry) Machines are present in the facility at Acanceh, Yucatan for help with shrinkage testing and some new product development. The facility contains a small set of 9 machines: 6 Washers and 3 Dryers designed for small loads of up to 50lbs.

Every new product developed has to first pass through PDL machines and then the quantity is multiplied and run on the industrial machines for production. Thus, it is important to know how the PDL and industrial washers and dryers perform and if their performance is correlated.

3.3.5.1 Designing of Experiment

The factors and levels for PDL are:

Factor 1: Fabric type- 2 Levels

- Bi-Blend
- Tri-Blend

Factor 2: Wash Type-4 Levels

- Rinse
- Hot Bleach
- Cold Bleach

Factor 3: Washer Type- 2 Levels

- PDL Washer 1
- PDL Washer 2

Factor 4: Dryer Type- 2 Levels

- PDL Dryer 1
- PDL Dryer 2

The DOE was designed using JMP Pro Version 14 …………...

Number of runs

*= (Fabric Type) *(Wash type) *(Washer Type) * (Dryer Temperature)*

*= (2) *(3) *(2) *(2)*

= 24

Table 11: DOE 1 for PDL vs Industrial Washers and Dryers Experiment

Factor	Fabric Type	Wash Type	Washer Type	Dryer Type
Run number				
1	Bi-Blend	Rinse	PDL Washer 1	PDL Dryer 1
2	Bi-Blend	Rinse	PDL Washer 1	PDL Dryer 2
3	Bi-Blend	Rinse	PDL Washer 2	PDL Dryer 1
4	Bi-Blend	Rinse	PDL Washer 2	PDL Dryer 2
5	Bi-Blend	Hot Bleach	PDL Washer 1	PDL Dryer 1
6	Bi-Blend	Hot Bleach	PDL Washer 1	PDL Dryer 2
7	Bi-Blend	Hot Bleach	PDL Washer 2	PDL Dryer 1
8	Bi-Blend	Hot Bleach	PDL Washer 2	PDL Dryer 2
9	Bi-Blend	Cold Bleach	PDL Washer 1	PDL Dryer 1
10	Bi-Blend	Cold Bleach	PDL Washer 1	PDL Dryer 2
11	Bi-Blend	Cold Bleach	PDL Washer 2	PDL Dryer 1
12	Bi-Blend	Cold Bleach	PDL Washer 2	PDL Dryer 2
13	Tri-Blend	Rinse	PDL Washer 1	PDL Dryer 1
14	Tri-Blend	Rinse	PDL Washer 1	PDL Dryer 2
15	Tri-Blend	Rinse	PDL Washer 2	PDL Dryer 1
16	Tri-Blend	Rinse	PDL Washer 2	PDL Dryer 2

Table 11 (Continued)

17	Tri-Blend	Hot Bleach	PDL Washer 1	PDL Dryer 1
18	Tri-Blend	Hot Bleach	PDL Washer 1	PDL Dryer 2
19	Tri-Blend	Hot Bleach	PDL Washer 2	PDL Dryer 1
20	Tri-Blend	Hot Bleach	PDL Washer 2	PDL Dryer 2
21	Tri-Blend	Cold Bleach	PDL Washer 1	PDL Dryer 1
22	Tri-Blend	Cold Bleach	PDL Washer 1	PDL Dryer 2
23	Tri-Blend	Cold Bleach	PDL Washer 2	PDL Dryer 1
24	Tri-Blend	Cold Bleach	PDL Washer 2	PDL Dryer 2

In Table 11 we can see the DOE for comparison between PDL and Industrial washers and dryers.

After the DOE for PDL washers and dryers was done, the same experiment was conducted using the industrial washers and dryers. All of the Factors remained the same except the Levels for Washer type and Dryer type were changed.

The levels for Washer type and Dryer type are:

Washer Type- 2 Levels

- Industrial Washer 1
- Industrial Washer 2

Dryer Type- 2 Levels

- Industrial Dryer 1
- Industrial Dryer 2

Table 12: DOE 2 for PDL vs Industrial Washers and Dryers Experiment

Factor	Fabric Type	Wash Type	Washer Type	Dryer Type
Run number				
1	Bi-Blend	Rinse	Industrial Washer 1	Industrial Dryer 1
2	Bi-Blend	Rinse	Industrial Washer 1	Industrial Dryer 2
3	Bi-Blend	Rinse	Industrial Washer 2	Industrial Dryer 1
4	Bi-Blend	Rinse	Industrial Washer 2	Industrial Dryer 2

Table 12 (Continued)

5	Bi-Blend	Hot Bleach	Industrial Washer 1	Industrial Dryer 1
6	Bi-Blend	Hot Bleach	Industrial Washer 1	Industrial Dryer 2
7	Bi-Blend	Hot Bleach	Industrial Washer 2	Industrial Dryer 1
8	Bi-Blend	Hot Bleach	Industrial Washer 2	Industrial Dryer 2
9	Bi-Blend	Cold Bleach	Industrial Washer 1	Industrial Dryer 1
10	Bi-Blend	Cold Bleach	Industrial Washer 1	Industrial Dryer 2
11	Bi-Blend	Cold Bleach	Industrial Washer 2	Industrial Dryer 1
12	Bi-Blend	Cold Bleach	Industrial Washer 2	Industrial Dryer 2
13	Tri-Blend	Rinse	Industrial Washer 1	Industrial Dryer 1
14	Tri-Blend	Rinse	Industrial Washer 1	Industrial Dryer 2
15	Tri-Blend	Rinse	Industrial Washer 2	Industrial Dryer 1
16	Tri-Blend	Rinse	Industrial Washer 2	Industrial Dryer 2
17	Tri-Blend	Hot Bleach	Industrial Washer 1	Industrial Dryer 1
18	Tri-Blend	Hot Bleach	Industrial Washer 1	Industrial Dryer 2
19	Tri-Blend	Hot Bleach	Industrial Washer 2	Industrial Dryer 1
20	Tri-Blend	Hot Bleach	Industrial Washer 2	Industrial Dryer 2
21	Tri-Blend	Cold Bleach	Industrial Washer 1	Industrial Dryer 1
22	Tri-Blend	Cold Bleach	Industrial Washer 1	Industrial Dryer 2
23	Tri-Blend	Cold Bleach	Industrial Washer 2	Industrial Dryer 1
24	Tri-Blend	Cold Bleach	Industrial Washer 2	Industrial Dryer 2

In Table 12 we can see the second part of the DOE for comparison between PDL and Industrial washers and dryers.

3.3.5.2 Performing of Experiment & Data Collection

After the design of experiment was completed, fabric swatches were cut according to the number of runs and coded. The runs were performed in the laundry section of VF Jean Manufacturing plant in Merida, Yucatan. A total of 4 Measurements were taken for each run (%)

- After wash fill
- After wash warp
- After dry fill
- After dry warp

A data collection sheet was created, and the measurements recorded.

4 Improve

After the analysis of the data, we moved to the improve phase where a lot of recommendations were put into place.

VF started to perform shrinkage tests on 100% of their Tri-Blend and Bi-Blend fabrics which was earlier at less than 40%. This helped them understand the shrinkage behavior of every single bale and thus led to decrease in shrinkage variation for the same fabric and same style. These improvements will be further discussed in Chapter 4 and 5.

5 Control

After VF started to work on the recommendations, they changed their measurement metric to Range of Fit and used Trend charts of their range by month to monitor continual progress

VF is in the process of large corporate changes and that the actual monitoring of the improved process will have to be studied later

CHAPTER 4: Results & Discussion

4.1 Gage R&R Results

The data from the Gage R&R were analyzed using JMP PRO version 14. A crossed Gage R&R was analyzed.

Variability Charts and Tables for Warp Shrinkage % & Fill Shrinkage %

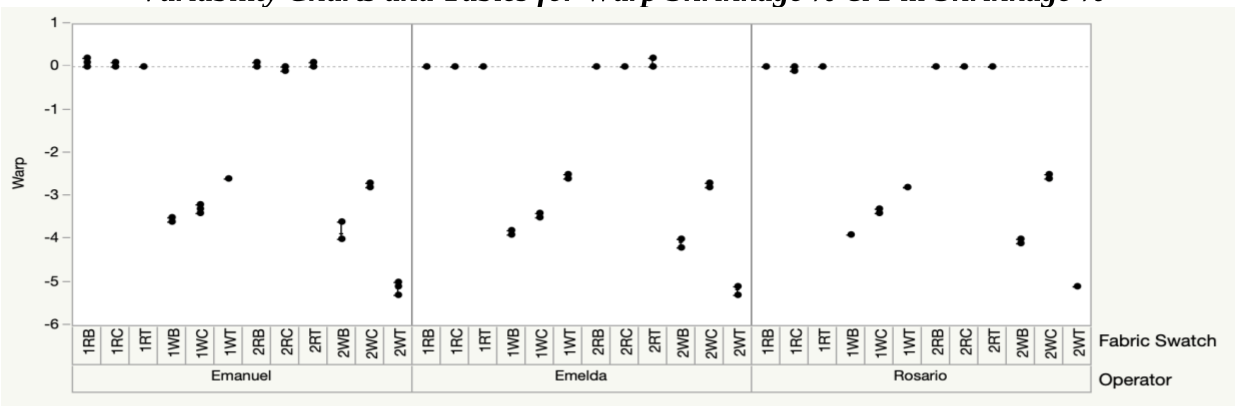


Figure 29: Data Points for Warp Shrinkage % Measurements by operators

From Figure 29 we can see the data points of warp Shrinkage % measurements for the three operators. We can see that all the operators have consistent means for their measurements.

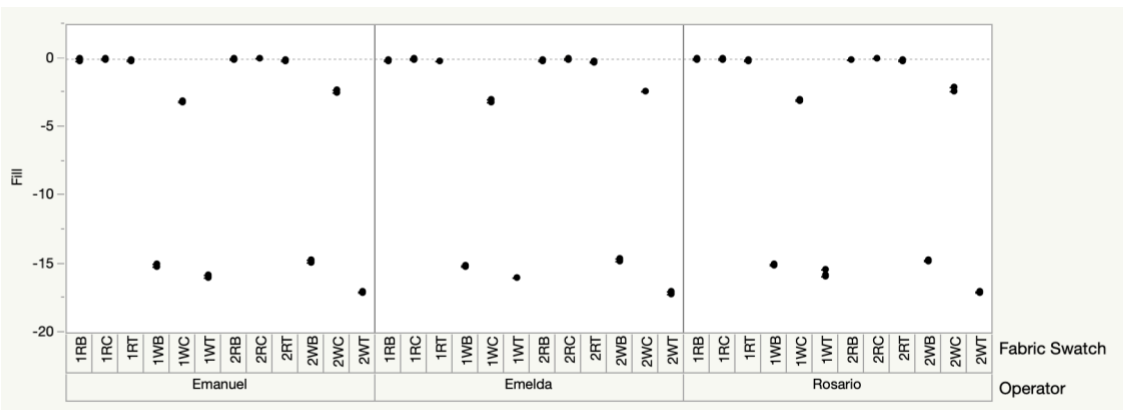


Figure 30: Data Points for Fill Shrinkage % Measurements by operators

From Figure 30 we can see the data points of Fill Shrinkage % measurements for the three operators. We can see that all the operators have consistent means for their measurements

Table 13: % Variance of components of Warp Shrinkage % Measurements

Component	Var Component	% of Total	
Gauge R&R	0.0104938	0.27	
Repeatability	0.0050926	0.13	
Reproducibility	0.0054012	0.14	
Part-to-Part	3.9459624	99.73	

Table 14: % Variance of components of Warp Shrinkage % Measurement

Component	Var Component	% of Total	
Gauge R&R	0.008981	0.0162	
Repeatability	0.007130	0.0129	
Reproducibility	0.001852	0.0033	
Part-to-Part	55.282360	99.98	

Mean Plot - Operator*Fabric Swatch Interaction

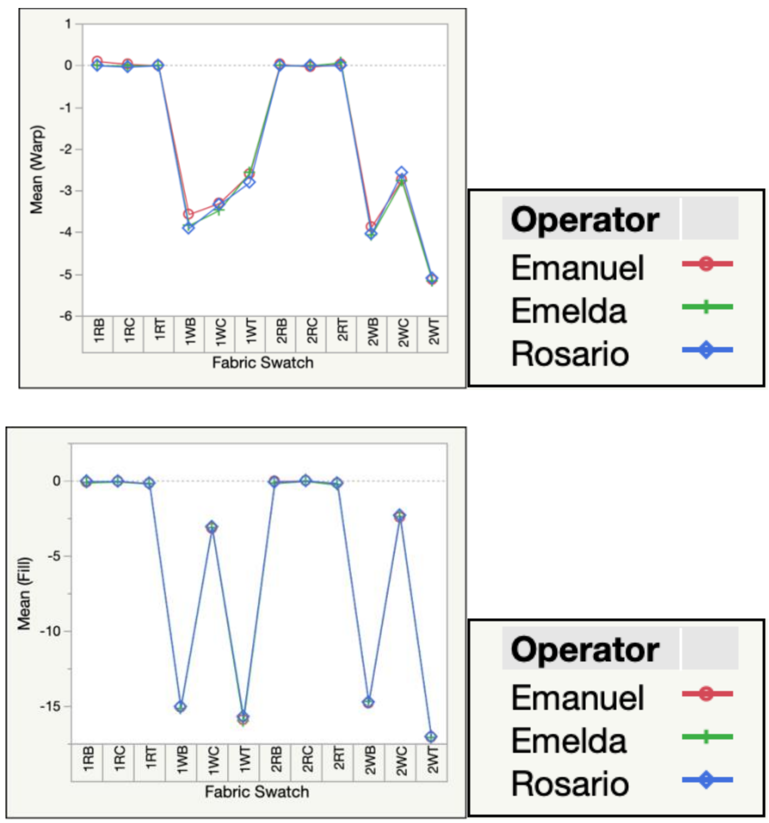


Figure 31: Gage R&R Mean Plots

From Figure 31 we see the mean plots of operator and fabric swatch interaction. We can see three lines for three operators and from the graphs it is evident that the means for all operator measurements are overlapping.

In order to feel comfortable using the measurement system, the results of the Gage R&R study should show that the R&R variation is less than 10% of the tolerance range.

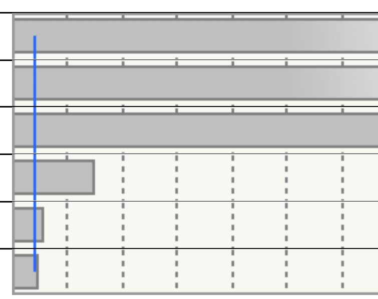
- Less than 10% = **ACCEPTABLE**
- Between 10% and 30% = **MARGINAL**
- Greater than 30% = **UNACCEPTABLE**

From Table 10 and Table 11 we can say that the measurement system is acceptable as the Gage R&R is 0.27% for the Warp shrinkage and 0.01% for the Fill shrinkage. Also, the part to part variation is over 99% for both the Fill and Warp measurements.

4.2 Screening Results

The data collected during the screening experiment was analyzed using JMP PRO 14 software. An ANOVA was performed. Tables 15 and Table 16 summarize the results of the effect tests.

Table 15: Effect Summary for After Wash Measurements

Source	Log Worth		PValue
Fabric Type	72.764		0.00000
Wash type	57.741		0.00000
Fabric Type*Wash type	37.890		0.00000
Wash type*Washer type	7.392		0.00000
Washer type	2.701		0.00199
Fabric Type*Washer type	2.390		0.00407

Using the p values in Table 15, it can be seen that all factors and all two-way interactions are significant.

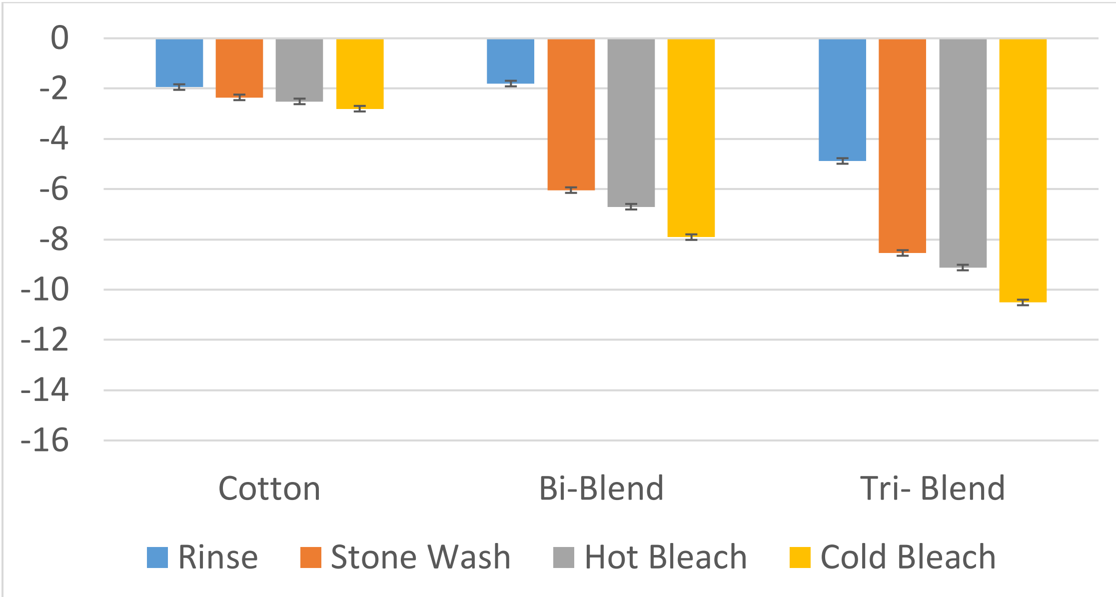


Figure 32: LS Means Interaction Plot of Fabric Type*Wash Type for After Wash Measurements

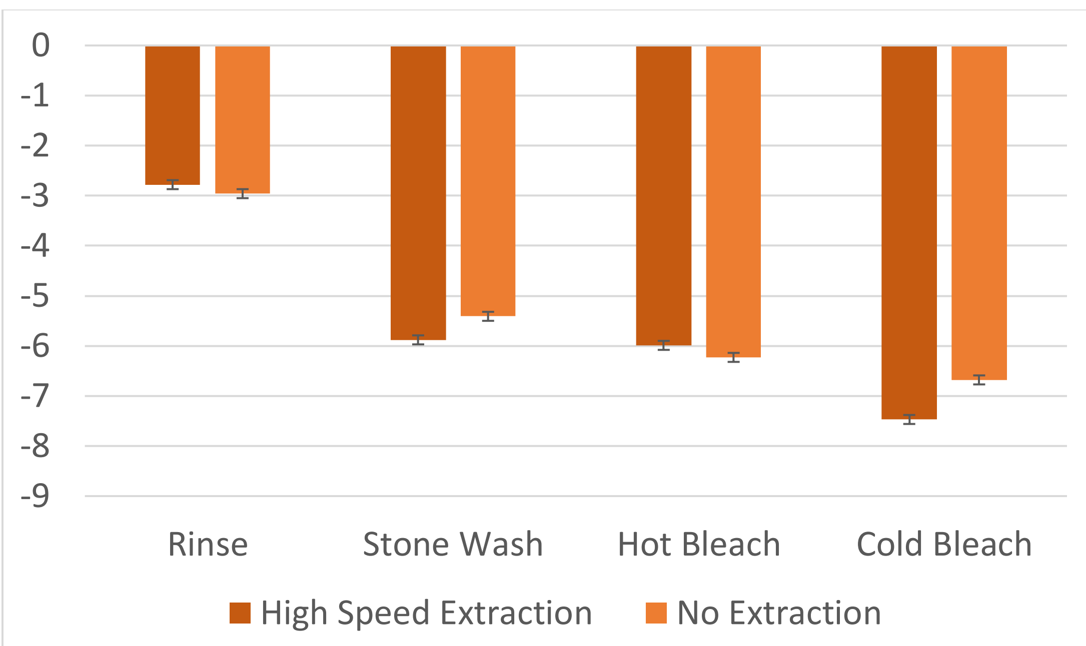


Figure 33: LS Means Interaction Plot of Washer Type*Wash Type for After Wash Measurements

From Figure 33 we can see washer type and wash type interaction is significantly different in Stone wash, Cold Wash and Hot Bleach Wash.

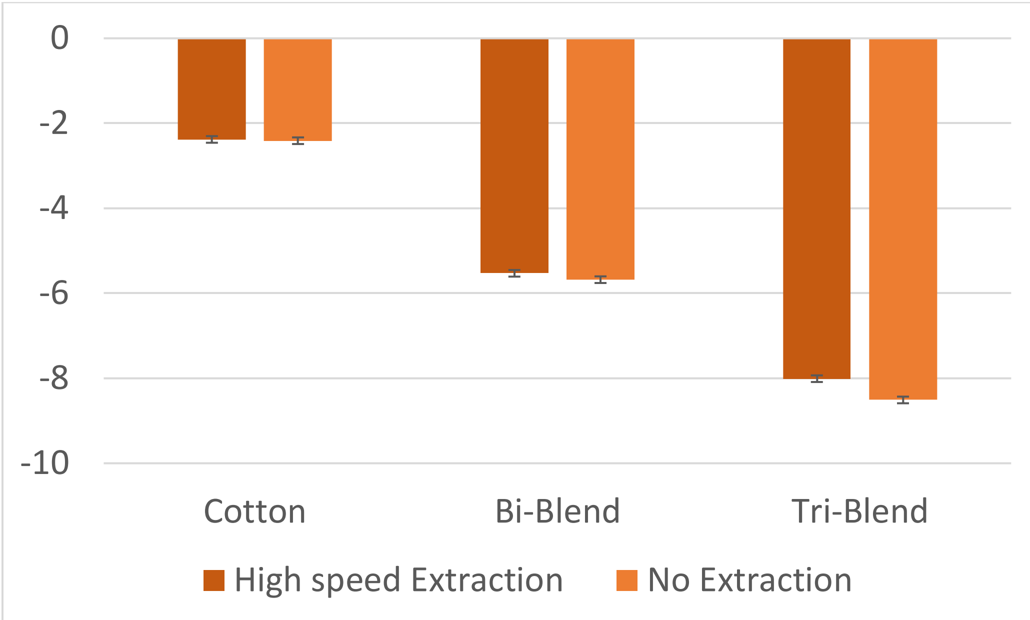


Figure 34: LS Means Interaction Plot of Fabric Type*Washer Type for After Wash Measurements

Table 16: Effect Summary for After Dry Measurements

Source	Log Worth		PValue
Fabric Type	73.071		0.00000
Wash type	34.032		0.00000
Fabric Type*Wash type	15.089		0.00000
Fabric Type*Dryer type	2.527		0.00297
Wash type*Dryer type	2.091		0.00810
Dryer type	0.550		0.28200

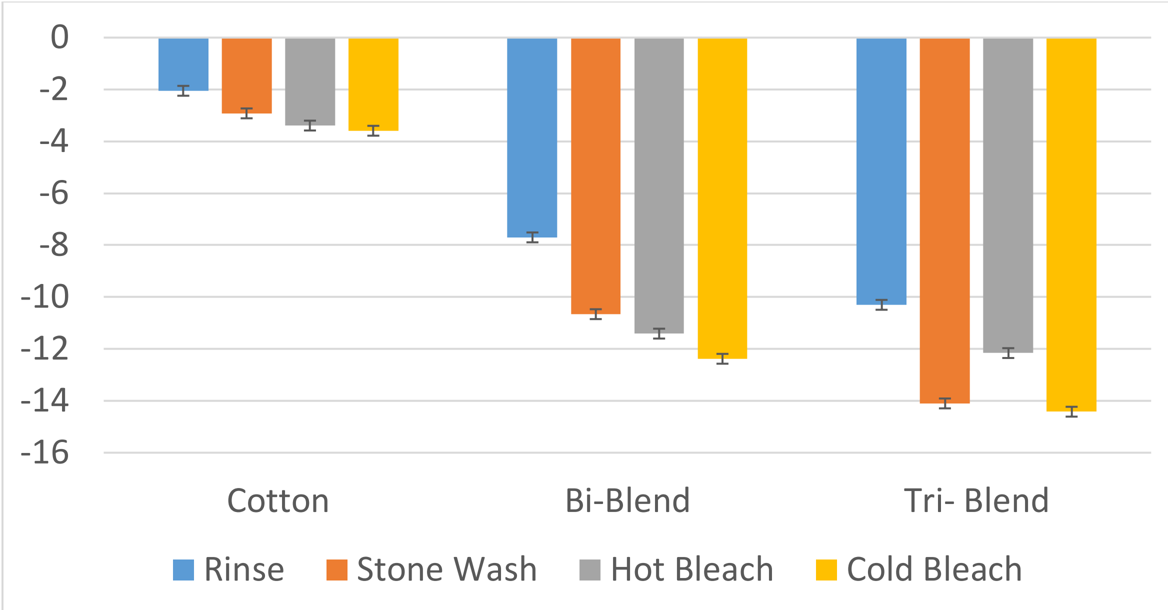


Figure 35: LS Means Interaction Plot of Fabric Type*Wash Type for After Dry Measurements

Figure 35 show similar variation in After dry measurements as it was seen in the After-wash measurements.

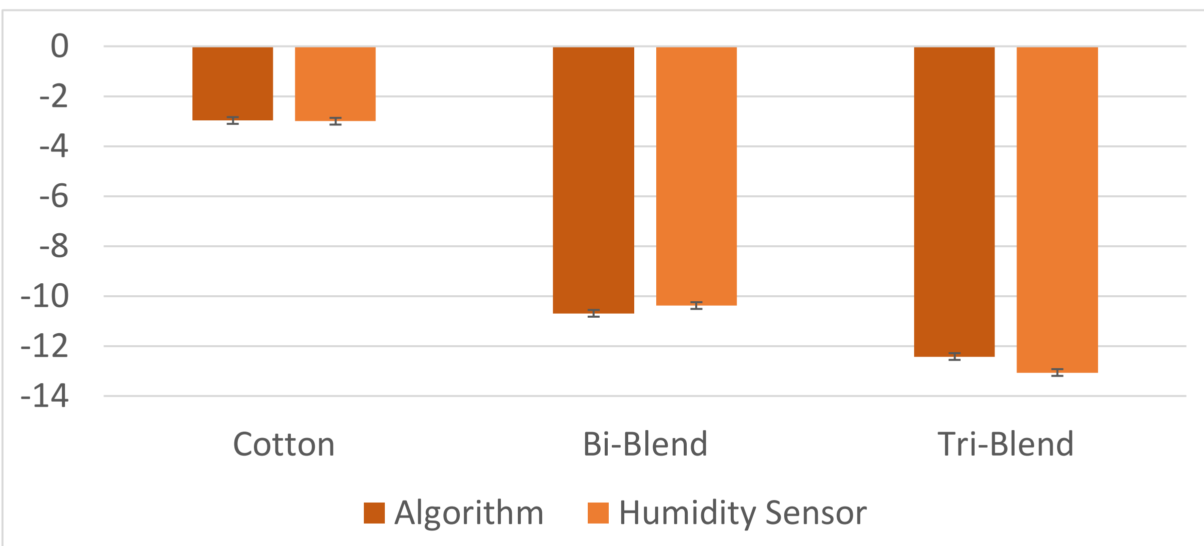


Figure 36: LS Means Interaction Plot of Fabric Type*Dryer Type for After Dry Measurements

From Figure 36, we understand that the interaction between dryers and Tri-Blend fabrics is significantly different.

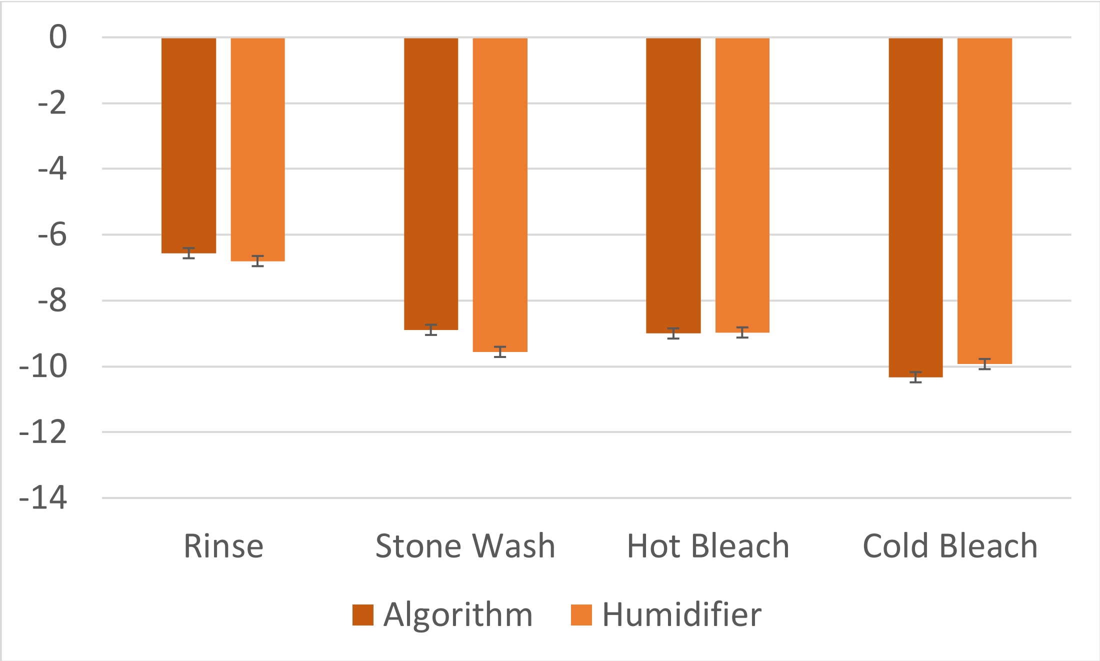


Figure 37: LS Means Interaction Plot of Wash Type*Dryer Type for After Dry Measurements

From Figure 37 we see that the interaction between wash type and fabric type was significantly different between stone wash, cold bleach wash and hot bleach wash.

Based on all these above results we went ahead and eliminated the factors Washer Type and Dryer Type. We also eliminated Cotton from our further studies due to its consistency in shrinkage. So, the further experiments were only performed with Tri-Blend and Bi-Blend Fabric.

4.3 Different PO Number Experiment Results

The data collected during the Different PO Number experiment was analyzed using JMP software. An ANOVA was performed. The p values for all factors and their levels are given below.

Table 17: Results for p Value of After Dry Measurements (Different PO Number)

Source	Log Worth		PValue
Wash Type	34.829		0.00000
Fabric Type*Wash Type	24.726		0.00000
Fabric Type*PO number	10.096		0.00000
PO number	9.197		0.00000
Fabric Type	2.350		0.00447
Wash Type*PO number	0.121		0.75667

From the above p values, we can see that the factors with a significant difference in their shrinkage were Wash Type, Fabric Type and PO number. We can also see the interactions between the Fabric Type and Wash Type, Fabric Type and PO number are significantly Different.

The Least Square Mean was used to display the factors being significantly different visually.

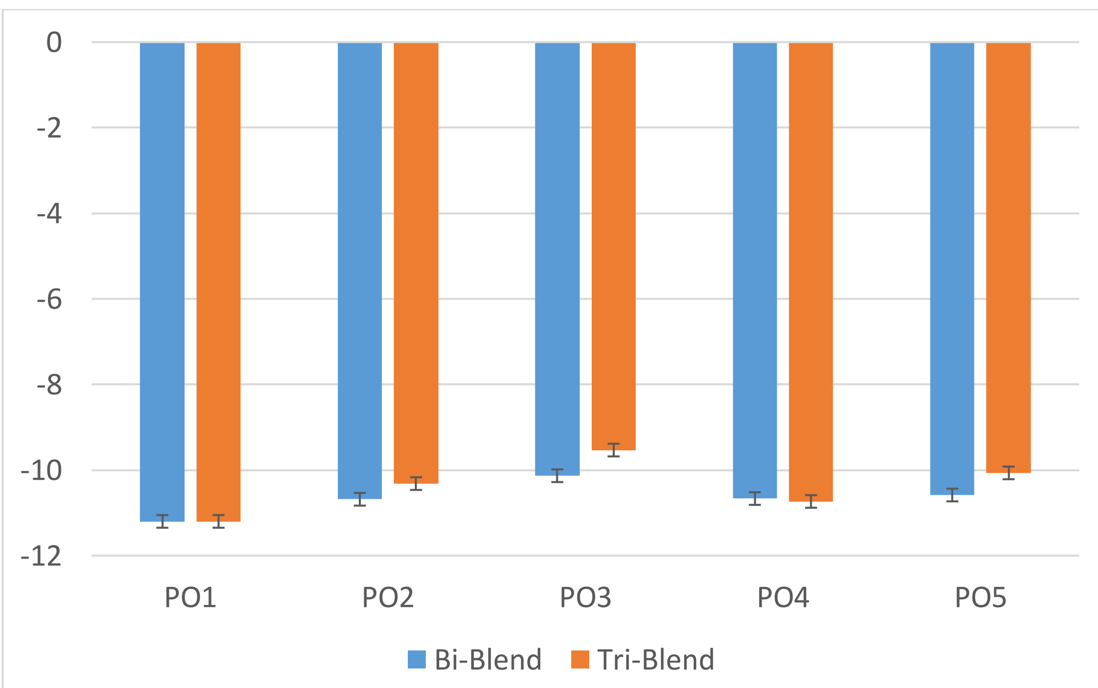


Figure 38: LS Means Interaction Plot of Fabric Type*PO number for After Dry Measurements

From Figure 38, we can see that the interaction between fabric type and Purchase Order number showed a significant difference.

4.4 Different Dryer Temperature Experiment Results

The data collected during the Different Dryer Temperature experiment was analyzed using JMP software. A full factorial ANOVA was performed. The p values for all factors and their levels are given below

Table 18: Results for p Value of After Dry Measurements (Different PO Dryer Temperatures)

Source	Log Worth		PValue
Fabric Type	3.606		0.000245
Dryer Temp	0.766		0.17135
Fabric Type*Dryer Temp	0.272		0.53515

From the above p values, we can see that there was no significant difference between dryer temperatures..

The Least Square Mean plot was used to display the factors that were significantly different.

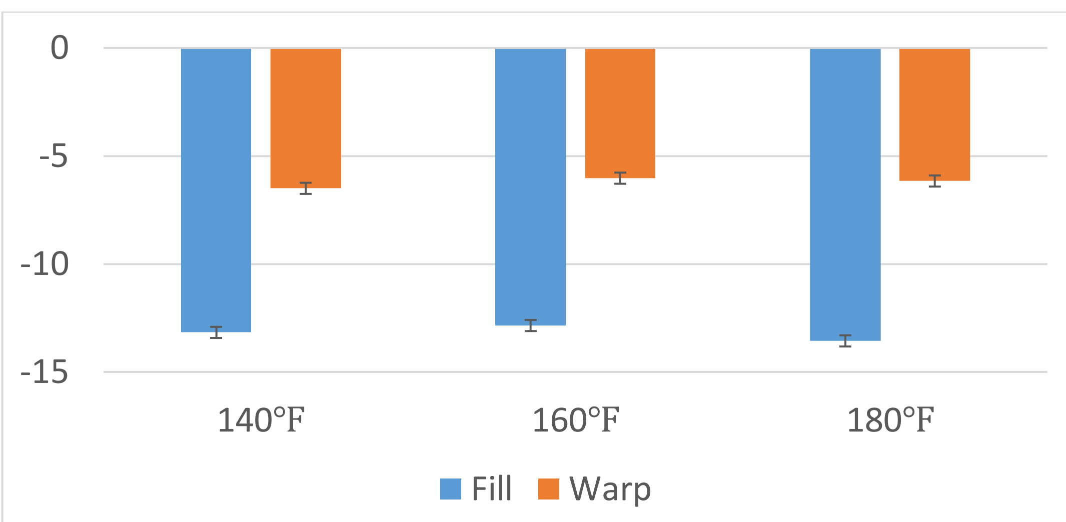


Figure 39: LS Means plot of Dryer Temperature Variation for After Dry Measurements

From Figure 39, we can see that dryer Temperatures are significantly different. But as this experiment was performed to understand if we can use the dryers at 140°F instead of 160°F and 180°F, and from the results we can see that it is not feasible.

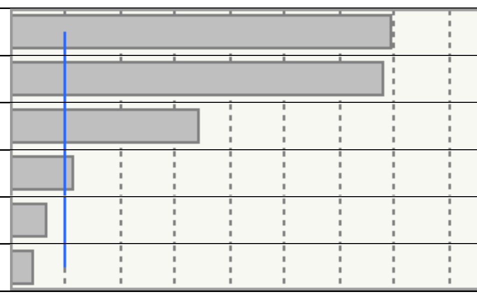
The fabrics at 140°F showed higher shrinkage because the cycle time at that temperature was 65 mins as opposed to 50 and 55 mins with 180°F and 160°F cycles respectively**.**

4.5 PDL & Industrial Washers and Dryers Comparison

The data collected during the PDL & Industrial Washers and Dryers Comparison experiment was analyzed using JMP software. A full factorial ANOVA was performed. The p values for all factors and their levels are given below.

Table 19: Results for p Value of After Wash Measurement (PDL Washers)

Source	**Log Worth**		**PValue**
wash type	13.869		0.00000
Fabric type	13.581		0.00000
Fabric type*wash type	6.857		0.00000
wash type*Washer type	2.295		0.00507
Washer type	1.350		0.04470
Fabric type*Washer type	0.861		0.13762



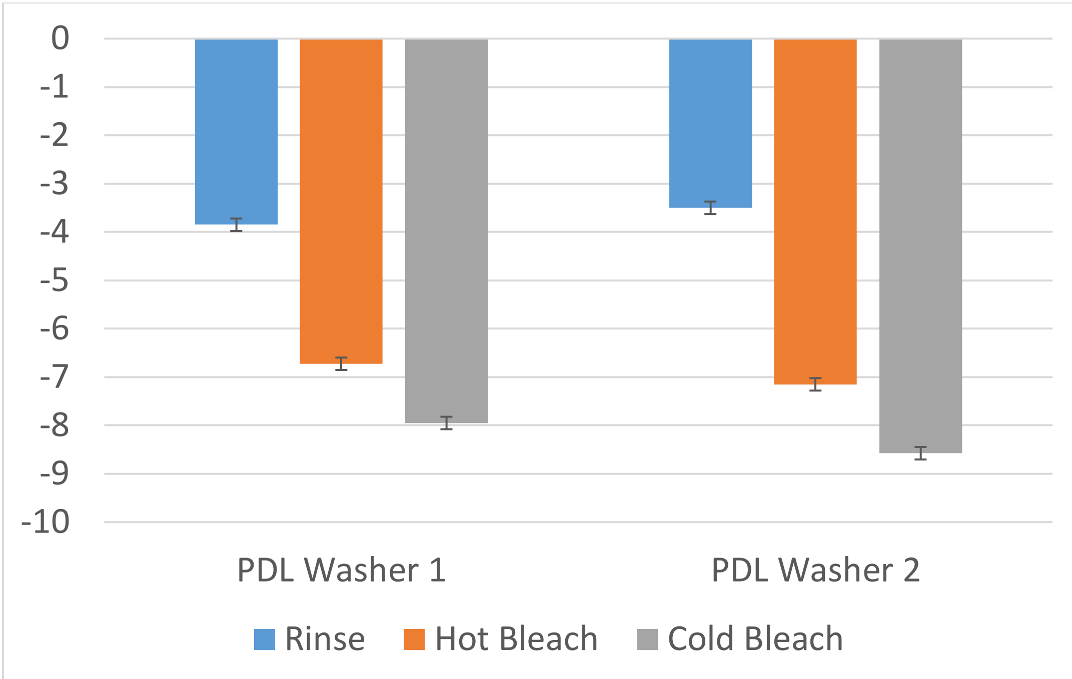


Figure 40: LS Means Interaction Plot of Wash Type*Washer Type for After Wash Measurements

Table 20: Results for p Value of After Dry Measurements (PDL Dryers)

Source	Log Worth		PValue
wash type	9.571		0.00000
Fabric type	7.533		0.00000
wash type*Dryer type	2.333		0.00464
Fabric type*Dryer type	0.517		0.30423
Dryer type	0.220		0.60289

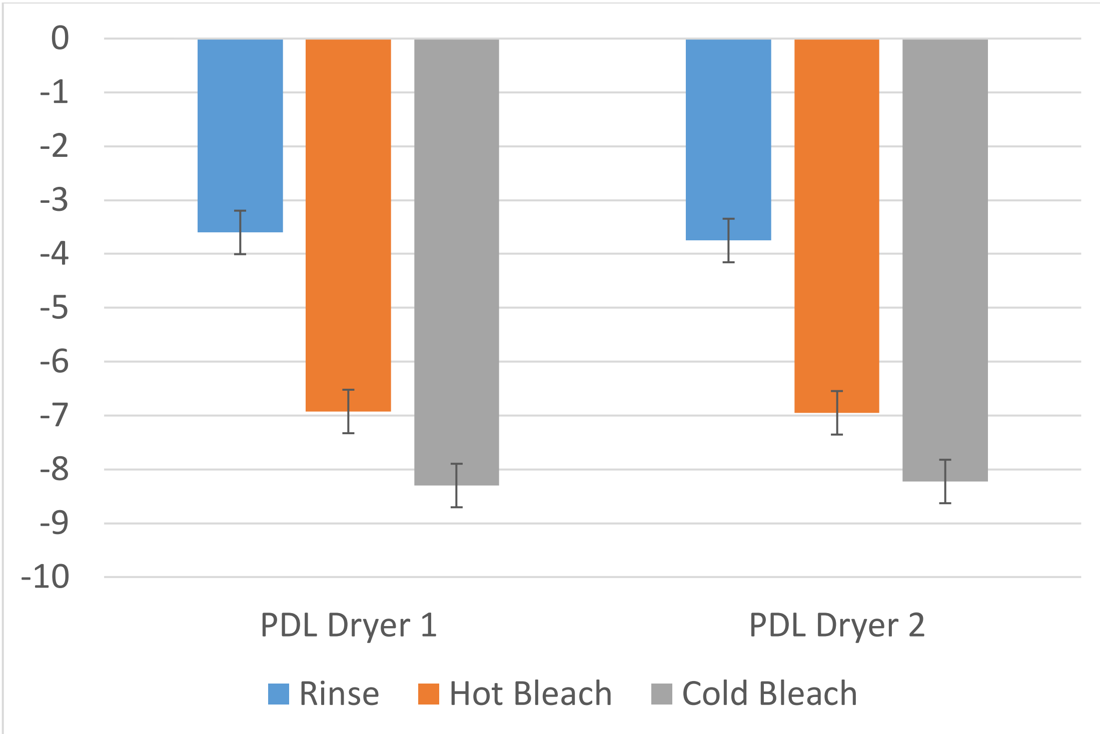


Figure 41: LS Means Interaction Plot of Wash Type*Dryer Type for After Dry Measurements

Table 21: Results for p Value of After Wash Fill (Industrial Washers)

Source	Log Worth		PValue
Wash Type	14.671		0.00000
Fabric Type	12.300		0.00000
Fabric Type*Wash Type	7.124		0.00000
Wash Type*Washer Type	2.083		0.00825
Fabric Type*Washer Type	1.334		0.04633
Washer Type	0.964		0.10874

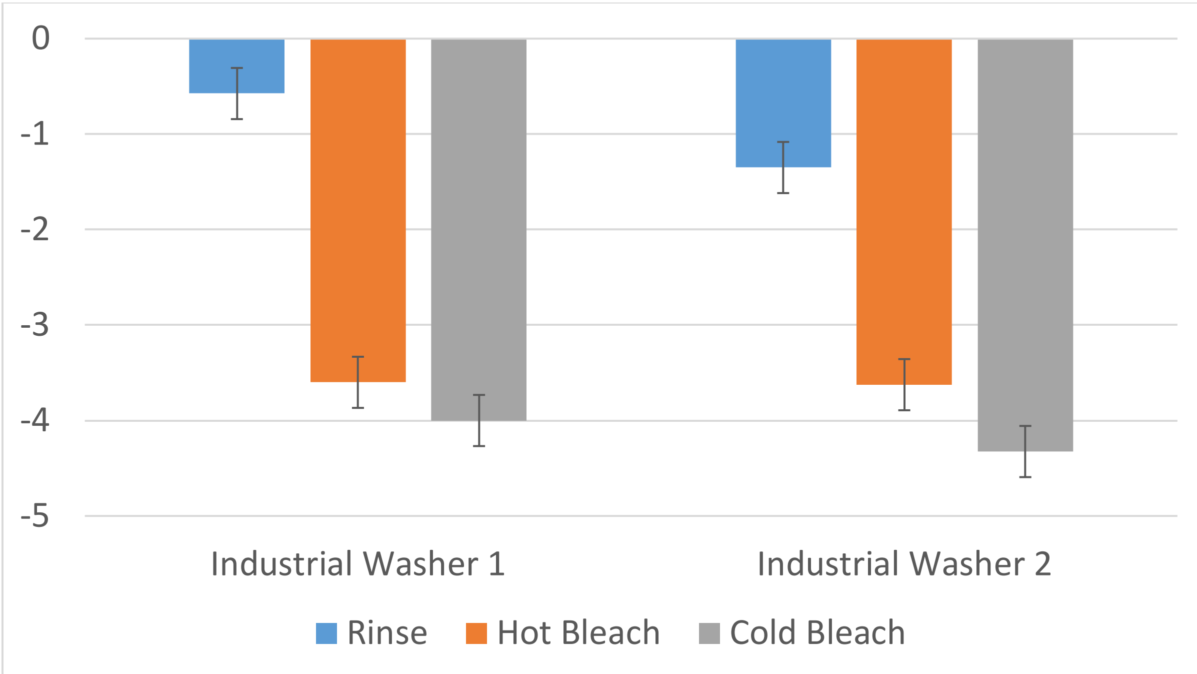


Figure 42: LS Means Interaction Plot of Wash Type*Washer Type for After Wash Measurements

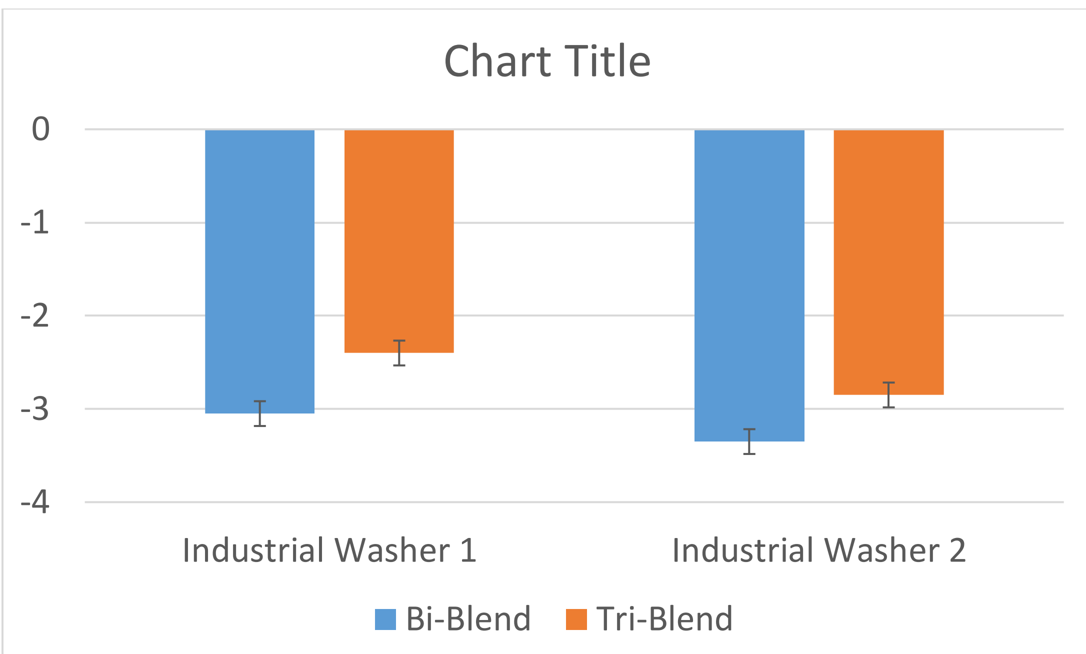
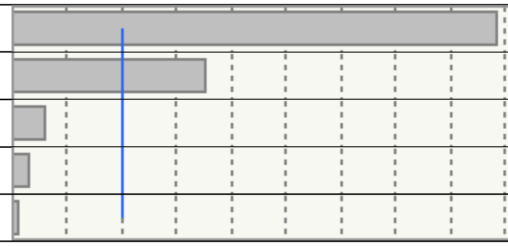


Figure 43: LS Means Interaction Plot of Fabric Type*Washer Type for After Wash Measurement

Table 22: Results for p Value of After Dry Fill (Industrial Dryers)

Source	Log Worth		PValue
Wash Type	8.844		0.00000
Fabric Type	3.560		0.00028
Fabric Type*Dryer type	0.599		0.25153
Dryer type	0.300		0.50153
Wash Type*Dryer type	0.136		0.73098



From the above p values, we can see that for the After Wash PDL Experiments, the interaction between PDL dryers and wash type was significantly different.

Industrial washers' interaction with wash type and fabric type was significantly different, but the industrial dryers did not show any difference.

We wanted to compare how the PDL washers and Dryers and the Industrial Washers and dryers compared with each other and if there was any difference between the measurements.

For this purpose, the Least Square Mean plots were used to display how the PDL washers and Dryers compare to each other.

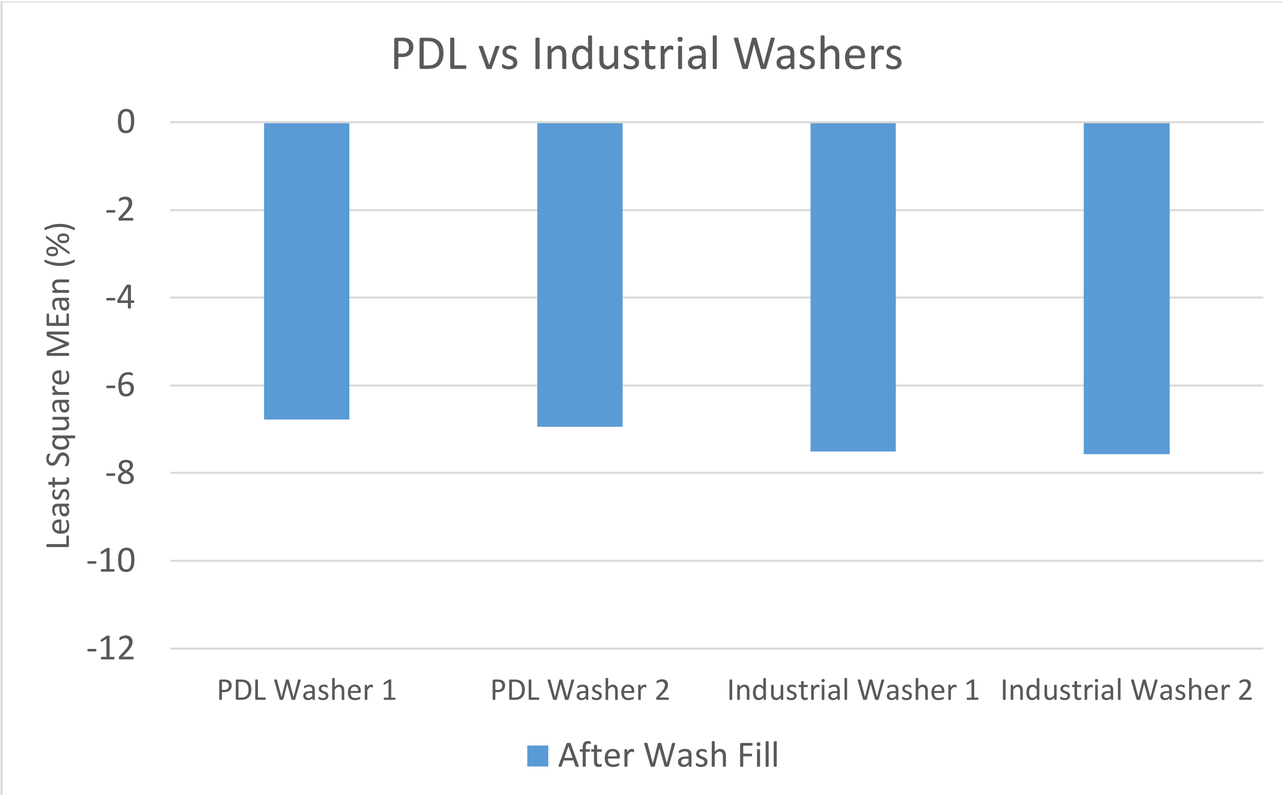


Figure 44: Comparison Between PDL and Industrial Washers

From the above graph we can understand that the PDL washer and industrial washers showed a significant difference between the measurements. There was about 0.8% shrinkage variation between PDL washers and Industrial Washers

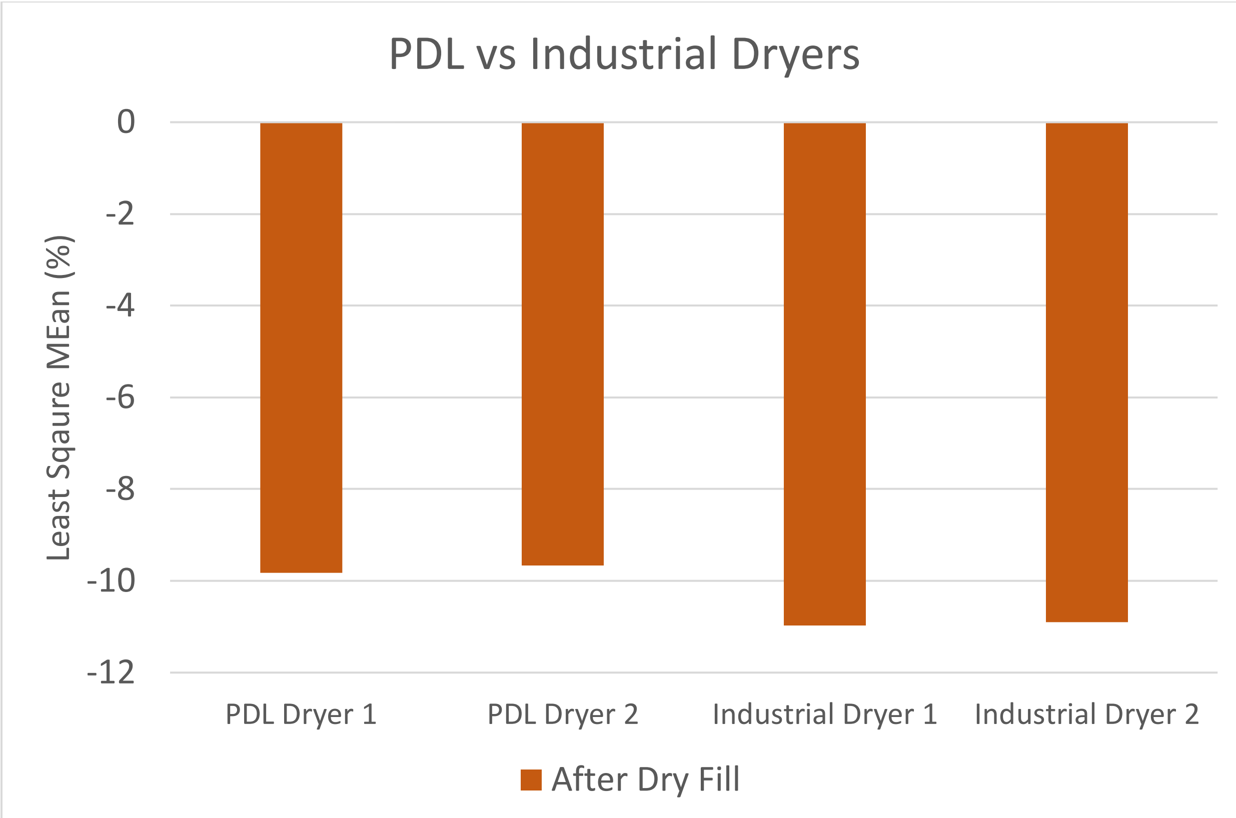


Figure 45: Comparison Between PDL and Industrial Dryers

Similarly, from the above graph we can see a significant difference between the PDL dyers and Industrial Dryers. There was about 1.3% shrinkage difference between the PDL and industrial Dryers.

After looking at the results it was decided that tri-blends and bi-blends need to be tested more in the production facilities to understand the behavior of each bale of fabric coming in from the mills. This was started in January and a trend chart of Range of fit was created.

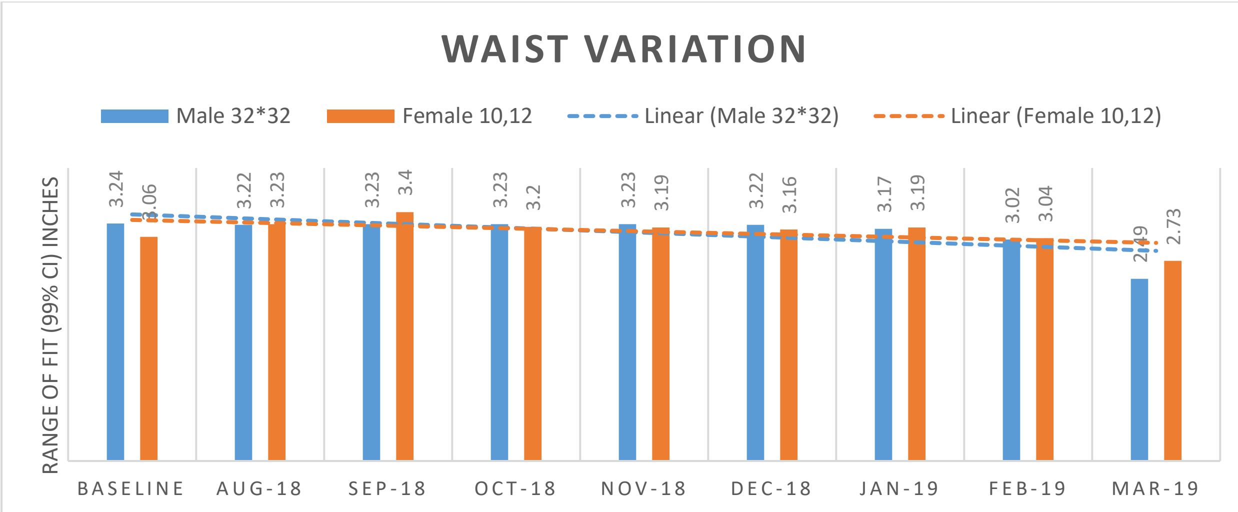


Figure 46: Trend Chart of Range of Fit (99% CI) from Jan 2018 to March 2019

From the above trend chart, we can see that the Range of Fit for Men's Waist variation has come down from 3.24" to 2.49" which is a 23.1% decrease in Range. Similarly, the Range of fit for women's Waist has come down from 3.12" to 2.73", which is about a 12.5% of reduction in Range of Fit.

CHAPTER 5: Conclusion & Future Scope

The goal of this research was to improve the VF Jeanswear company's fit variation. This was done by using DMAIC – a Lean Six Sigma process improvement methodology. At the end of the project, we understood a lot about how this variation is caused and how it can be gradually improved.

The Fit consistency was significantly improved by applying the recommendations in the finishing facility like increasing the testing from about approximately 40% to 100%. We can see a significant decrease of 23.1% in Range of Fit of Men's Waist and 12.5% reduction in Range of Fit of Women's waist.

5.1 Future Scope

5.1.1 Fabric Type:

From the results it is clear that 100% cotton shows an excellent fit consistency, but the real problem is with the two other fabrics which are a major portion of Denim Production-

- Bi-Blends
- Tri-Blends

These fabrics showed a lot of variability throughout the experiments. I think this problem can be gradually fixed by studying these fabrics overtime. Currently VF only samples 5 Bales out of every PO for shrinkage testing. A PO can consist of anywhere between to 15-50 bales of fabric. As VF starts sampling 100% of the Bales for Bi-Blends and Tri-Blends, they were able to understand the behavior of the fabric better and were able to put these bales in the right Shrinkage buckets which helped them in reducing the variation between same fabric garments.

5.1.2 Wash Type

The Wash Type had a significant impact on Shrinkage Variation. Cold Bleach and Hot Bleach Wash types showed the most shrinkage. So, we can study the different types of bleach further or can replace it with newer chemicals which can give us a similar appearance without causing an extensive shrinkage.

5.1.3 Working with Mill Data

Different PO numbers showed varied shrinkage for the same exact fabric and same exact recipes. This is a big reason for the overall variation as there are no improvements that we can make further in the process that can stop this.

Hence to improve this variation VF needs to start working with the Mill closely and collect the Data from the mill which could help them understand the variability beforehand and could set certain standards which will help with the denim shrinkage consistency.

5.1.4 Dryer Temperature at 140°F

The Different Dryer Temperatures experiment was performed, but it did not give us information from the results for VF to switch to140°F from 160°F for their Tri-Blend and Bi-Blend Fabrics.

5.1.5 PDL and Industrial Machines Correlation

PDL and industrial machines showed a 1% difference in shrinkage. As there are multiple washers and dryers in both PDL and Production, we could do testing for all of the machines to get a good picture of how they all perform. This will help reduce the machine variation that is currently present in the manufacturing process.

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APPENDIX

Screening Experiment After Wash ANOVA

Summary of Fit

RSquare	0.991316
RSquare Adj	0.989424
Root Mean Square Error	0.312609
Mean of Response	-5.42708
Observations (or Sum Wgts)	96

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	17	870.15819	51.1858	523.7770
Error	78	7.62250	0.0977	**Prob > F**
C. Total	95	877.78069		<.0001*

Screening Experiment After Dry ANOVA

Summary of Fit

RSquare	0.98806
RSquare Adj	0.985457
Root Mean Square Error	0.539513
Mean of Response	-8.75771
Observations (or Sum Wgts)	96

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	17	1878.7512	110.515	379.6789
Error	78	22.7038	0.291	**Prob > F**
C. Total	95	1901.4550		<.0001*

Different Po Number Experiment After Dry ANOVA

Summary of Fit

RSquare	0.988902
RSquare Adj	0.982769
Root Mean Square Error	0.363052
Mean of Response	-10.5117
Observations (or Sum Wgts)	60

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	21	446.31317	21.2530	161.2434
Error	38	5.00867	0.1318	**Prob > F**
C. Total	59	451.32183		<.0001*

Different Dryer Temperature Experiment After Dry ANOVA

Summary of Fit

RSquare	0.675416
RSquare Adj	0.579242
Root Mean Square Error	0.814521
Mean of Response	-13.5083
Observations (or Sum Wgts)	36

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	37.274500	4.65931	7.0229
Error	27	17.913000	0.66344	**Prob > F**
C. Total	35	55.187500		<.0001*

PDL After Wash ANOVA

Summary of Fit

RSquare	0.994277
RSquare Adj	0.990598
Root Mean Square Error	0.259234
Mean of Response	-6.29167
Observations (or Sum Wgts)	24

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	9	163.45750	18.1619	270.2575
Error	14	0.94083	0.0672	**Prob > F**
C. Total	23	164.39833		<.0001*

PDL AFTER WASH ANOVA

Summary of Fit

RSquare	0.936455
RSquare Adj	0.908654
Root Mean Square Error	0.808033
Mean of Response	-6.29167
Observations (or Sum Wgts)	24

Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	7	153.95167	21.9931	33.6844
Error	16	10.44667	0.6529	**Prob > F**
C. Total	23	164.39833		<.0001*

INDUSTRIAL AFTER WASH ANOVA

Summary of Fit

RSquare	0.994453
RSquare Adj	0.990887
Root Mean Square Error	0.326872
Mean of Response	-6.95417
Observations (or Sum Wgts)	24

Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	9	268.16375	29.7960	278.8704
Error	14	1.49583	0.1068	**Prob > F**
C. Total	23	269.65958		<.0001*

INDUSTRIAL AFTER DRY ANOVA

Summary of Fit

RSquare	0.853244
RSquare Adj	0.789038
Root Mean Square Error	1.365497
Mean of Response	-10.525
Observations (or Sum Wgts)	24

Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	7	173.45167	24.7788	13.2892
Error	16	29.83333	1.8646	**Prob > F**
C. Total	23	203.28500		<.0001*