ABSTRACT

CLAUDIA ECHEVERRIA MAGARIÑOS. Yarn Specifications and Performance Metrics for Short Staple Yarn Manufacturers. (Under the direction of Dr. George Hodge and Dr. William Oxenham).

Domestic yarn manufacturers must address the requirements of all the participants in the textile and apparel supply chain in order to remain competitive and to differentiate their products from offshore sources. The objective of this research was to better understand these requirements through visits to companies, elaboration of case studies, discussions and interviews with members of the supply chain.

Case studies were conducted with the participation of machinery, yarn, fabric and apparel manufacturers, as well as research and retail organizations. Both domestic and Latin American companies were pursued; a total of 32 company interviews were conducted involving 64 participants. These interviews were used to map the yarn specification process across the supply chain; identify yarn characteristics most frequently specified; identify how the characteristics are measured and their importance as a function of the final product. The products investigated were denim, t-shirts, socks, sheets and sewing thread made of cotton or poly-cotton blends.

Yarn specification across the supply chain includes three basic yarn characteristics, yarn count, yarn type (spinning system), and fiber content. Retailers put more emphasis specifying fabric characteristics rather than yarns characteristics. Detailed yarn characteristics such as Uster® % CV, tensile properties, and surface characteristics are usually decided at the fabric

and yarn manufacturing level, based on the fabric specifications and the requirements for an optimum process performance.

Methods and equipment used to test fabrics and yarns are relatively standard for both domestic and international companies. Analyses of different software used to manage product data revealed that these are not used to their full extend and detailed yarn characteristics are rarely incorporated into final product design.

It was also possible to identify performance metrics and several business practices that can bring domestic yarn manufacturers closer to the retailers and to drive business success. These practices were identified not only through discussions with yarn manufacturers, but from feedback at the fabrication and retail levels. Good business relationships, availability, capacity and location were found to be key drivers for success for commodity yarn producers and it was found that they should try to reinforce relationships with the vendors rather than directly with the retailers. Innovation and flexibility allow specialty yarn manufacturers to have direct access to retailers and designers. Yarn quality, price and delivery can typically be considered “order qualifying criteria” as opposed to a means of product differentiation.

Yarn Specifications and Performance Metrics for
Short Staple Yarn Manufacturers

by
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BIOGRAPHY

Claudia Echeverría Magariños was born in Cochabamba, Bolivia June 23, 1978. She graduated from the Universidad Privada Boliviana (UPB) in 2001 with a B.S. degree in Production Engineering. After graduation, she worked for five years at America Textil S.A., the largest textile and apparel company in Bolivia, in positions at the manufacturing, planning and product development areas. In 2002, Claudia was transferred from the company's fabric mill planning department to the sewing plant, in charge of the sample room, and was part of the team that formally established the Product Development Department of the company. She worked in Product Development until July 2006 as a Development Officer, in charge of Polo Ralph Lauren, Abercrombie & Fitch, and other accounts. In the fall of 2006, with the desire of expanding her knowledge in textiles, empower her professional career, and receiving a Fulbright Scholarship and Institute of Textile Technology Fellowship, she decided to pursue a Master of Science in Textile Management and Technology at North Carolina State University. After graduation, Claudia will move to New York to start her job with Mast Industries as a Production Coordinator for Victoria's Secret Direct division.

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1 INTRODUCTION

In order to remain competitive and to be able to differentiate their products from off shore sources, domestic yarn manufacturers must address the requirements of all the participants in the textile and apparel supply chain. Unfortunately, the communication and collaboration along the supply chain is limited, and yarn manufacturers are far removed from the final consumer.

The objective of this research was to better understand these requirements through visits to companies, elaboration of case studies, discussions and interviews with members of the supply chain, and by identifying yarn specifications and performance metrics that are important to yarn buyers and the other participants of the textile and apparel supply chain. Based on the research findings, domestic yarn manufactures will be able to target the yarn characteristics and specifications that will allow them to get the orders and remain competitive.

There are many ways to specify yarns and yarn is often considered as a generic input to the fabric production process, but has a large impact on the suitability of the final product. This research also evaluated how product data management systems for garments and fabrics incorporate the complexity of the yarn in the design of the final products.

Performance measures play three simultaneous roles: as an objective, as a metric or measurement tool, and as a reward mechanism and they are used to support the decision making process (Loch & Kavadias, 2008).

This project identified what are the performance metrics that companies in the textile and apparel supply chain consider when evaluating supplier's performance, these do not only include technical specifications, but financial, delivery, and service.

The researched focus was on domestic manufacturers of cotton and poly/cotton yarns for applications such as jeans, t-shirts, sheets, socks and sewing thread. A summary of relevant data regarding U.S. imports and exports of these final products, as well as yarn commerce, is presented in chapter two.

1.1. Research Limitations

This research was focused on cotton and poly/cotton yarns for applications such as jeans, t-shirts, sheets, socks and sewing thread; therefore results may not be generalized to other products.

Data was obtained from a non-probability convenience sample of domestic and Latin American companies, focusing on the interaction of the different components of the textile and apparel supply chain and domestic yarn manufacturers. Although the sample is believed to be representative, results can not be generalized to the entire population of the U.S. textile and apparel industry.

Despite the effort to contact the most knowledgeable people in the areas of study at the various companies interviewed; respondents might not have had access to all the data required to answer the questions or have not been completely familiar with all the areas covered by the research, and this might represent a potential inability error.

1.2. Research Objectives

The main objective of this research was to identify and better understand the requirements of the different components of the textile and apparel supply chain in regards to yarn specifications and performance metrics. Satisfying these requirements could allow domestic yarn manufacturers to remain competitive and differentiate their products from off-shore sources. Keeping that in mind, seven research objectives were formulated:

- RO1. Map the yarn specification process across the supply chain.
- RO2. Identify yarn specifications considered important to yarn manufacturers, yarn buyers and other participants of the supply chain.
- RO3. Identify current standard testing methods and equipment used to evaluate yarn properties.
- RO4. Identify the most important yarn specifications as a function of the final product.
- RO5. Identify performance metrics used by yarn manufacturers, yarn buyers and other participants of the supply chain.

- RO6. Define “order qualifying and order winning criteria” for domestic yarn manufacturers that will allow them to remain competitive and differentiate their products from offshore sources.
- RO7. Evaluate existing product data management systems as to how they incorporate yarn characteristics into designing the final product.

1.3. Research Significance

Mapping the yarn specification process enabled the identification of links of the textile and apparel supply chain that govern the generation of yarn specifications. This will allow yarn manufacturers to define what type of relationships they need to promote with the companies at these specific links.

By identifying the most important yarn specifications for the products investigated, domestic yarn manufacturers will provide goods that address customer requirements in the textile and apparel supply chain, and they will have the chance to incorporate this information in product data management systems that allow going back to the fiber and yarn stages when developing a new product.

Yarn specifications play an important role in several areas in a company. In the areas of marketing and sales, for example, specifications are used for advertisement; especially if they can show that their products are of a better quality compared to competitors’ products.

Yarn specifications are also used as a communication tool with customers, since they describe in detail the characteristics of a product and provide the information required for negotiating prices and contracts.

In the manufacturing area, the description of the characteristics and composition of the materials used to produce a product allows companies to plan the production, to identify the type of machinery and assign human resources and time required to make a product. They also set the parameters to produce consistent products.

Specifications are required in logistics when sourcing and negotiating with suppliers. Presentation of raw materials, transportation, lead times, storage conditions, environmental regulations and compliances, and price, are some of the factors that will influence the decisions made when selecting a supplier.

Knowing the performance metrics considered important to yarn buyers and the other components of the textile and apparel supply chain, will allow yarn manufactures to target the “order winning criteria” to remain competitive. Members of the supply chain will recognize where domestic yarn manufacturers provide a preferred product and service.

Chapter two of this document presents a review of relevant literature including the dynamics of U.S. textile and apparel industry and its supply chain, yarn characteristics, standard testing methods and machinery used to measure yarn characteristics.

Business related issues like performance metrics and order winning criteria, are also described in chapter two.

Chapter three provides theoretical support and a description of the methodology used to conduct the research. And the last section of the document, chapters four and five present the findings, conclusions and recommendations of the research.

2 LITERATURE REVIEW

The literature reviewed can be grouped in three main areas:

- The first area includes the status of the U.S. textile and apparel industry and the supply chain in relation to the manufacturing, imports and exports of yarns and final products selected for the research.

- The second area focused on yarn characteristics frequently specified in the U.S. as well as the standard testing methods and the equipment available to measure those characteristics. A review of product data management systems was also done at this stage, to see how they could incorporate yarn characteristics into the product development process.

- Finally, the third area involved the study of performance metrics as well as the definition of winning and qualifying order criteria.

2.1. Textiles and Apparel in the U.S.

The report about world textile and apparel trade and production trends, presented by Textile Outlook International (March – April 2007) indicates that the U.S. consumer expenditure on clothing and footwear grew by 4.9% to $358.6 bn in 2006, following increases of 4.6% in 2004 and 5.1%in 2005.

Clothing stores, warehouse clubs and superstores have been the two segments of the U.S. retailer market that have benefit the most.

The report also indicates that the imports of cotton clothing in 2006 grew by 5.2% to 13,458.5 mn sme (square meters equivalent) in terms of volume and by 5.5% to $43,411.5 mn in value terms. It was observed a decrease in the volume and value of imports of apparel made of wool, man-made fiber, silk blends, and non-cotton vegetables fibers.

The imports of cotton knitted shirts (women's, men's, girl's and boy's combined) were the most robust (2457.5 mn sme) and 599.2 mn sme (an annual increase of 16.9%) of cotton hosiery. The main suppliers for clothing were China (28.9 % market share), Mexico (6.6%), Bangladesh (5.8%) and Honduras (5%). For textiles products, the largest suppliers were China (40.9% market share), Pakistan (9.8%), Canada (7.7%) and Mexico (6.6%).

As per the exports, the Textile Outlook International (2007) report indicated that U.S. clothing exports fell by 3.4% to $4,317 mn in 2006. The main reason was the decrease of exports of clothing parts and semi-finished clothing to Mexico and Caribbean Basin initiative (CBI) countries, especially parts of brassieres, trousers and knitted t-shirts.

Foreign demand for U.S. textiles products increased by 2% in 2006 to $12,385.4 mn. Mexico remained as the largest market for U.S. textile products, followed by Canada, Honduras and Dominican Republic.

Of the top twenty markets for U.S. textile exports, the Chinese market was the fastest growing destination in terms of value. Exports to China increased during 2006 by 30.2% due to the demand of uncarded/uncombed cotton (absorbent fiber for personal care and surgery applications) and nonwoven fabric.

Production, import and export statistics were collected from the Current Industrial Reports made by the U.S. Census Bureau, for carded and combed cotton yarns. As observed in Table 1, U.S. exports represented 38% of the domestic production of carded cotton yarns. Due to missing data (no available to date), it was not possible to calculate the total domestic production of combed cotton yarns, but as per Table 2, exports of combed cotton yarns represent 96% and 98% of the domestic production for the last quarters of 2007.

As per the Office of Textiles and Apparel (OTEXA), from the exports of yarn in general made in 2007, 30% went to Honduras, 14% to Canada, 11% to Mexico and 10% to Dominican Republic.

Table 1. 85% or more cotton, carded yarn. Source: U.S. Census Bureau

	U.S. Production [thousands of Kg.]	U.S. Imports [thousands of Kg.]	**U.S. Exports [thousands of Kg.]**
First Quarter 2007	204,938	6,640	**70,136**
Second Quarter 2007	199,353	5,774	**72,807**
Third Quarter 2007	190,602	5,206	**73,960**
Fourth Quarter 2007	181,515	3,971	**72,769**
Total	776,408	21,591	289,672

Table 2. 85% or more cotton, combed yarn. Source: U.S. Census Bureau

	U.S. Production [thousands of Kg.]	U.S. Imports [thousands of Kg.]	**U.S. Exports [thousands of Kg.]**
First Quarter 2007	12,991	10,059	**10,439**
Second Quarter 2007	xxx	9,499	**11,208**
Third Quarter 2007	11,190	9,563	**10,764**
Fourth Quarter 2007	12,174	8,217	**11,968**
Total	xxxx	37,338	44,379

2.1.1 T-Shirts Market

As the majority of apparel items, most trade in t-shirts involves exports from developing countries to the E.U., the U.S., and other industrialized nations. The reasons are the low cost labor in developing countries where generally is cheaper to produce t-shirts, and the strong demand in the markets of developed countries, where household incomes are relatively high. (Sekhar, Nov-Dec 2007).

In 2006, the largest market for t-shirts is the E.U., followed by the U.S. which had an estimated 17% share of global imports, valued at $4.4 bn. While the main suppliers in 2006 for the E.U. were Turkey, Bangladesh, China and India; for the U.S. Mexico supplied 15.4% of the t-shirt imports, followed by Honduras (14.6%), El Salvador (8.8%) and Haiti (5.4%).

Gildan Activewear, Hanesbrands and Delta Apparel are leading t-shirt manufacturers which have their headquarters in North America. As part of their supply chain strategies, they are developing low-cost production centers abroad in order to improve their competitiveness and gain market share in the U.S.'s intensely competitive t-shirt market. (Sekhar, Nov-Dec 2007).

2.1.2 Denim Market

Another report presented by Sekhar (May-June 2007) on denim fabric indicated that global exports grew an average of 5% per annum to reach $4.3 bn in 2005. Denim has the advantage of being durable, has a wide range of consumer appeal, there are continuous innovations in design and style, and it can be sold at a wide range of price points.

In order of value, the top ten denim fabric exporting countries in 2005 were: China, Hong Kong, the U.S., Italy, Turkey, Japan, India, Brazil, Spain and Pakistan, all together accounted the 83% of total world denim exports. Curiously, most of the leaders in this market have an abundant domestic supply of raw cotton and foreign markets which are located in close proximity. (Sekhar, May-June 2007)

Between 2001 and 2005 U.S. denim exports have decrease 1% annually, due to the intense competition from low cost Asian countries and the downturn in the Mexican denim apparel industry, the U.S. main customer. The U.S. exports in most of the cases to its neighboring countries; its competitiveness has been supported by its geographical proximity and by trade agreements which help to combat low cost Asian manufacturers. 68% of denim fabric exports were shipped to Mexico, during 2001-2005, and 21% were sold to Guatemala, Canada and Colombia. As per the imports, in 2005, Mexico was largest importer of denim with 14.6% of global imports, followed by Hong Kong 13,2% and Turkey with 10.7%. (Sekhar, May-June 2007)

U.S. denim production decreased during January to September 2006 by 38% compared with the corresponding period of 2005. The reasons were that Mexico imports decreased 27%, the increase of imports from Italy of higher priced denim fabric used in fashionable denim apparel and the relocation of operations of U.S. denim apparel manufacturers to South America and China.

2.1.3 Sheets Market

The US market for cotton bed sheets offers a clear view of the low-cost revolution. Pakistan now attracts more than 50% of the import market with China taking another 22%. U.S. production sharply decreased in 2005 and 2006. Total U.S. imports of printed cotton bed sheets were up 88% in volume terms in 2005, the first year without quotas, further rising 62% in January-August 2006. Non printed cotton bed sheet imports more than doubled in volume terms in 2005 before modestly increasing 10% in the first eight months of 2006. (Emerging Textiles, 2006)

U.S. imports from Pakistan were more than 30 million units in 2005. Imports from China exceeded 10 million pieces in 2005. Both countries together account for more than 77% of US imports. According to official data, domestic production of cotton and man-made fiber sheets fell 30% in 2005 before further sliding 38% in the first quarter of 2006, while imports were up 49.80% and 44%, respectively. The share of domestic production in the US market fell from 73% in 2001 down to 31% in 2005 and 23.8% in the first quarter of 2006. (Emerging Textiles, 2006)

2.1.4 Socks Market

The U.S. sock industry was the most competitive sector of the domestic apparel industry left in 2004. The imports of socks grew from less than 1 million dozen pairs in 2001 to 22 million dozen pairs in 2003, while their average wholesale price dropped from $9.0 to 4.15 over the same period. U.S. sock production decreased from 207 million dozen pairs in 2001 to 166 million dozen pairs in 2003, and domestic market share has dropped from 76% in 1999 to 40% in 2004. (Bealer, 2004)

In the present, U.S. socks producers are concerned about the surge in socks from Mexico that occurred when the North American Free Trade Agreement went into effect; the increase in imports from Asia, and also from Honduras under the Central American Free Trade Agreement. During the first half of 2006, 6.7% of the U.S. socks imports came from Honduras; a year after, during the same period, imports from Honduras represented 10.2% or 12.3 million dozen pairs, of cotton, wool and man-made fiber. The reason was partly because of duty free treatment under CAFTA. (Clark, 2007)

U.S. socks producers represented 33.2% of the total U.S. socks market in 2006 compared to a 37.9% in 2005. In the present they are requesting the government to reestablish quota limits on Chinese and Honduran socks imports. Opponents of new restrictions to Honduran imports would help Asian suppliers but hurt U.S. textile companies, since Central America is their largest market for yarns. (Clark, 2008)

2.2. Supply Chain and the DAMA Project

The Supply chain is the process that integrates, coordinates and controls the movement of goods, materials and information from a supplier through a series of intermediate customers to the final consumer. (Emmett & Crocker, 2006).

Supply Chain Management (SCM) involves the management and linking of activities such as sourcing, making, moving and selling, between suppliers and customers to the consumer in a timely manner. It offers opportunities for competitive advantages by service differentiation and cost leadership. (Emmett & Crocker, 2006).

In today's markets, relationships play an important role when selling and buying products. Some of the benefits of maintaining good relationships and collaboration in the supply chain are shown in Table 3.

The key factors for establishing successful collaborative relationships include sharing information, top management support, shared goals, early communication to suppliers and supplier contribution to value. (Emmett & Crocker, 2006).

Table 3. Benefits of collaboration in the supply chain. Source: Emmett & Crocker, 2006.

Aspect	Collaboration brings
Forecast accuracy	Increase external visibility will force better accuracy.
Lead Time	Reductions following sharing and joint improvements.
Inventory	Reduce as stock levels fall.
Utilization of resources	Improve in a leaner operation with less waste.
Costs	Reduced and improved.
Service levels	Increased and improved.
People	Trust and improved relationships.

In 1993 a project called DAMA (Demand Activated Manufacturing Architecture) was initiated as part of the American Textile Partnership Program (AMTEX) sponsored by industry, the Department of Energy, federal agencies, and universities. DAMA focused on increasing the competitiveness of the fiber, textile, sewn products, and retail domestic industries by developing an inter-enterprise architecture and analysis methodology for supply chains that enables improved collaborative business across the supply chain. (Chapman and Peternsen, 2000. $Lovejoy_A$).

DAMA's goals included:

- **Supply Chain Analysis:** Complete development, validation, and transfer to industry of the methodology for performing supply chain analysis to provide opportunity identification, synchronization, and improved high-level business process access leading to cost, time, and quality improvements in the U.S. textile and apparel industry.

- **Supply Chain Architecture:** Develop, validate, and publish an inter-enterprise supply chain architecture to provide current information at an inter-enterprise level, leading to improved planning, JIT, and inventory management for all participants.

The project last seven years, industry determined that collaborative business practices are necessary to provide a significant reduction in time and cost to product supply chains and the opportunity for savings in the U.S. softgoods industry was estimated at $45 billion per year with a realistically achievable 50% reduction in time. The vision of the project demanded industry to focus on consumers, to develop a supply chain management process that would be demand driven and where production had to be synchronized to replenish product at the consumer's pull rate. The Internet was chosen as the tool used to share information selectively and securely across the supply chain.

The results of the project are summarized in the DAMA Final Report (Chapman and Petersen, 2000. Lovejoy$_B$, 2001):

- **Supply Chain Analysis:** Four textile products were selected to track and document their production process, analyze the relationship and business processes between companies participating in the production and also the data and information flow generated in all the stages.

  The information was gathered thought visits to plants and interviews with key managers. As a result, process step maps for each product were developed and they included the fiber, textile, sewn products, and retail business processes. These maps displayed the activities necessary for the production of a product and revealed improvement opportunities.

They also lead to the study of the relationship of the business processes and the exchange of data, as a result, the Quick Response Apparel Business Model, the Textile Industry Supply Chain Business Model, and a Logistics Process Map for Assembly in Mexico, were created.

- **Supply Chain Architecture:** the textile and apparel supply chain consists of a number of companies, which convert a raw or semi-finished supplied material (e.g. cotton, or fiber) into a state of completion and greater value, resulting in the production of a consumer product, sold through retail.

  It was found that software programs where not enough to share corporate information. The key architecture for collaboration across the supply chain is the support of a common set of information available to all members of the supply chain. The information must be timely, accurate and secure. The inter-enterprise architecture and the Collaborative Industry Supply Chain Simulation (CISS) model were developed to show how a single demand plan was visible to all members of the chain and how that information would be processed and shared with each company participating.

  To validate DAMA Supply Chain Architecture, simulation tools were used to calculate planning/production lead-time, order lead-time and inventory levels for the various partners in the supply chain.

The results showed that there was a reduction of 16 days in the order lead-time using the collaborative supply chain model versus the traditional supply chain model, which was a 49% decrease. Also, the collaborative model reduced 137 days from the planning / production cycle which represented a 49% decrease in time in the supply chain. For each partner, in the collaborative model, there was a reduction in finished goods inventory from just over 6 weeks worth of units to approximately 2.5 weeks of inventory while providing the same level of customer service.

2.3. Standard Testing Methods

According to the terminology standards of the Textiles Committee (D13) and the Sports Equipment and Facilities Committee (F08) of the American Society for Testing and Materials (ASTM); a specification is defined as: *A precise statement of a set of requirements to be satisfied by a material, product, system or service that indicates the procedures for determining whether each of the requirements is satisfied. D123,D13.*

A document setting forth pertinent details of a product, such as performance, chemical composition, physical properties and dimensions, prepared for use in, or to form the basis for, an agreement between negotiating parts. F869,F08

The Non Destructive Testing Committee (E07) of the American Society for Testing and Materials (ASTM) defines Standard as *(1) a physical reference used as a basis for comparison or calibration; (2) a concept that has been established by authority, custom, or agreement to serve as a model or rule in the measurement of quality or the establishment of a practice or procedure. E1316, E04*.

As observed, the term standard can refer to an actual test method or to the minimum acceptable level of performance on a particular test (Collier & Epps, 1999). In this section we will refer to the standard test methods, to those testing procedures widely accepted to test yarn properties.

There are many organizations in the U.S. and the rest of the world that defined terms, established standards and developed methods to test properties of textiles along the supply chain. Only those organizations specific to this research will be described.

2.3.1 American Society for Testing and Materials (ASTM)

ASTM is the world's largest nongovernmental standards writing body. It consists of more than 130 technical committees dealing with materials used in many industries besides textiles. ASTM is international in scope and publishes an Annual Book of Standards. The standards are released when a full consensus of all concerned parties is met. ASTM voting members vote in proposed standards and revisions, once published; they are reviewed, reaffirmed or withdrawn every five years. (Kadolph, 2007)

For fibers and yarns, considered the “dry” side of the industry, most of the standards fall under ASTM Technical Committee D13 – Textiles, this committee typically develops test methods dealing with fiber and yarn evaluation and properties.

ASTM Technical Committee D13 has thirty sub-committees; from those, the four highly related to yarns are:

- D13.58 Yarns and Fibers
- D13.92 Terminology
- D13.93 Statistics
- D13.99 Coordination Committee for ISO & Foreign Textile Standards

Appendix A contains the list of ASTM standards highly related to the yarns investigated in this research.

2.3.2 American Association of Textile Chemists and Colorists (AATCC)

AATCC typically develops standard test methods for evaluating colored or chemically treated textile materials; they cover the “wet” side of the industry because most of the dyeing and finishing procedures used in textiles are performed in water.

AATCC standard test methods are developed by research committees and they are approved by three-level hierarchy before they are published in the “Technical Manual”.

Test methods are reviewed annually for the three years of existence after had been published; then, they will be revised, reaffirmed or withdrawn every five years. (Kadolph, 2007)

AATCC and ASTM are both based in the U.S. and they work very closely together to keep each organization aware of the others activities to reduce the possibility of duplication. Both organizations periodically do joint development work. A complete list of the testing methods offered by AATCC can be found at http://www.aatcc.org/Technical/Test_Methods/Alpha_List.htm. Since their focus is on the chemistry and coloration of textile materials, they offer testing methods for fiber analysis and fabric performance, but not for yarns specifically.

2.3.3 International Organization for Standardization (ISO)

ISO coordinates many voluntary standardization organizations worldwide and addresses many industries also. Because of the global nature of many industries, standard processes and terminology for determining the quality and performance of materials and products are becoming increasingly important. (Kadolph, 2007)

The Technical Committee in charge of Textiles is the TC 38. Three of the ISO/TC38 subcommittees:

- TC 38/SC 1 Tests for colored textiles and colorants
- TC 38/SC 2 Cleansing, finishing and water resistance tests
- TC 38/SC 20 Fabric descriptions
- TC 38/SC 23 Fibers and yarns
- TC 38/SC 24 Conditioning atmospheres and physical tests for textile fabrics

AATCC is secretariat subcommittees SC1 and SC2 and Subcommittee SC23 is secretariat by Cotton Inc., another U.S. organization. Both work to get the United States practices and standards approved globally.

Additionally, ISO has two programs that facilitate companies to participate in the international trade. ISO 9000 certifies that a company meets the criteria for business-to-business interaction. ISO 1400 enables companies to formulate, implement and audit policies related to their impact on the environment. (Kadolph, 2007)
The list of ISO standards for textiles can be found at www.iso.org and a selection of the standards directly related to the yarns investigated in this research is shown in Appendix B.

2.4. Yarn Characteristics and Specifications

Yarn is often considered as a generic input to the fabric production process, but has a large impact on the suitability of the final product. The characteristics of a yarn can affect the physical properties of the fabric such as appearance, hand, comfort, drape, durability, and cost. At the same time, yarn characteristics, will influence the efficiency of the fabric formation process.

"In order to specify a property it is also necessary at the same time to specify the method of test" (Saville, 1999). In his book, Saville describes in detail the yarn properties and the methods and apparatus used to measure them.

Lord (2003) and McCreight et al. (1997) focus in describing the production processes of yarns, the different technology systems available to obtain short staple, long staple and filament yarns, the influence of the machinery settings in the yarn characteristics, operational factors as well as production efficiencies and quality considerations.

Kadolph, S.J. (2007) offers definitions of standards and specifications, explains the role of quality and quality assurance techniques, such as Total Quality Management and analytical tools, applied to the complete manufacturing process, from fiber to final product, with emphasis in fabrics and garments.

After reviewing existent literature about yarn processing and testing, it was observed that the yarn characteristics most frequently specified in books are:

Table 4. Frequently used yarn characteristics

Frequently used yarn characteristics	
Fiber type and content	Yarn Strength
Yarn type	Yarn Elongation
Yarn structure	Friction Coefficient
Yarn count (Linear density)	Neps count
Yarn twist	Yarn Bulk
Yarn evenness (Thick and thin places)	Yarn Texture (Texturizing process, crip structure)
Yarn hairiness	Yarn Finish

Quality level of the yarn is appreciated from different points of view depending on the market and the end use. For example, a yarn with a tenacity of 17.3 [cN/tex] can be used in knitting applications but it will break constantly if it is used for weaving, since yarns are exposed to higher stress while weaving. Elongation on the other hand needs to be higher for a knitting yarn than in a weaving yarn.

One can continue giving examples of how yarn properties could affect the transforming processes from yarn to fabric and the characteristics of the fabric. If yarns are grouped in four major categories: type of fibers, yarn structure, yarn twist and spinning system and there are 10 variations in each of these categories, by simple probability there will be 10^4 different types of yarn (Behery, 2005); imagine the amount of different fabric qualities you can obtain from them.

So at the end, when trying to establish the characteristics that define a “good yarn” the answer will be “It all depends…”; knowing two things for sure, that the yarn and subsequent fabrics must have an acceptable blend of performance, aesthetics and reasonable price for a specific end use, and that the final quality measure will be “can the yarn be sold?” and even more important “will there be repeat orders?”. (Oxenham, 2005)

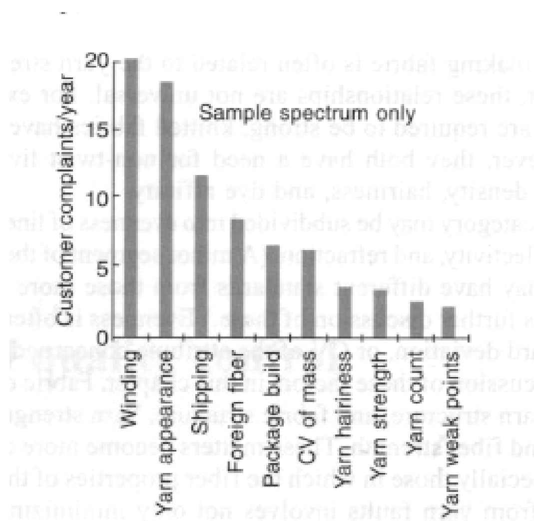


Figure 1. Spectrum of complaints. Source: Lord, 2003.

“The analysis of customer’s complaints is a prime tool for keeping track of quality levels” (Lord, 2003). Lord makes a good point by showing graphically the frequency of yarn quality complaints for fine staple yarns (Figure 1).

It can be observed that sometimes technical issues are not as important as operational or managerial issues, like shipping for example. Additionally, winding and yarn appearance, the two most common complaints, are problems caused by more than one factor and not always by a physical property of the yarn. Winding could represent many other issues, including bad processing practices and yarn appearance could cover thin and thick places, neps, etc.

2.5. Testing Equipment

This section describes the most common equipment use in the laboratories of domestic yarn manufacturers to control the quality of their products.

2.5.1 Uster Technologies AG

Uster Technologies is a supplier of electronic equipment to control the quality in the yarn manufacturing process. The information contained in this section was obtained from the vast number of articles that can be found on the website www.uster.com and Uster® application report series. Table 5 shows the different characteristics of the yarns that can be measured and the specific name of the Uster® equipment necessary to do it.

Although the Uster® Tensojet and the Uster® Tensorapid have the same applications of testing tensile strength and both utilize the CRE (constant rate of extension) principle to apply force to the tested specimen, they are two totally different instruments.

The Uster® Tensorapid uses the traditional method of pneumatic clamps with one stationary and one moving clamp.

Table 5.Description of yarn characteristics measured with Uster® equipment. Source: Uster® Statistics 2007.

Yarn Characteristics	Description	Unit	Machine
Count variations (CV_{cb})	Count variations between packages	%	Uster® Tester
Mass variations (CV_m)	Coefficient of variation of mass	%	Uster® Tester
Mass variations (CV_{mb})	Coefficient of variation of mass between packages	%	Uster® Tester
Imperfections (Thick/Thin/Neps)	Number or thick places, thin places and neps.	1/1000	Uster® Tester
Hairiness (H)	Absolute value of hairiness. Measurement of the entire fiber length		Uster® Tester
Standard deviation of hairiness (S_H)	Standard deviation of hairiness within a package		Uster® Tester
Coefficient of variation of hairiness	Variation of hairiness between packages	%	Uster® Tester
Trash (Dust/Trash)	Dust and trash in yarns. Counts refer to 1000 m of	1/1000	Uster® Tester
Coefficient of variation of the	Variation of the yarn diameter	%	Uster® Tester
Shape	Shape of the yarn-cross section/Ratio of the axes of		Uster® Tester
Density (D)	Density of the yarn	g/cm^3	Uster® Tester
Strength (F_H)	Breaking force	cN	Tensorapid &
Tenacity (R_H)	Breaking force referred to the yarn count	cN/Tex	Tensorapid &
Coefficient of variation of tenacity	Variation of the individual values of tenacity	%	Tensorapid &
Elongation (ε_H)	Yarn elongation at breaking force	%	Tensorapid &
Coefficient of variation of elongation	Variation of the individual elongation values	%	Tensorapid &
Work done to break (W_H)	Work performed during tensile testing of yarns at	cNcm	Tensorapid &
Coefficient of variation of work done	Variation of the individual values of work done to	%	Uster® Tensojet
Weak places in the yarn/strength	0.1% of all tests have a strength below this value	cN	Uster® Tensojet
Weak places in the yarn/elongation	0.1% of all tests have a elongation below this value	%	Uster® Tensojet
Weak places in the yarn/strength	0.01% of all tests have a strength below this value	cN	Uster® Tensojet
Weak places in the yarn/elongation	0.1% of all tests have a elongation below this value	%	Uster® Tensojet

The clamp speed is completely stepless and can be selected anywhere from 50 to 5000 mm/minute, this maximum speed and with a clamp distance of 50 cm, have been recognized as a common test method. The clamp distance is also stepless, and can be set from 10 to 100 cm.

It is important to note that there are other test standards that use different speeds and clamp distances, as a result, different strength and elongation values will occur; therefore it is very important that when tensile tests are reported the testing parameters are also specified (speed, clamp distance, pre-tension, etc).

The Uster® Tensojet uses a patented system of two pairs of metal and rubber coated rolls to carry out tensile testing, this design allows the machine to operate at much higher speeds (400 m/min) than traditional tensile testers.

The high speed has two distinct advantages:

- It more closely duplicates the stress that the yarn is subjected to in weaving.
- The larger sample size (standard test - 1000 breaks, 800 meters of yarn) is a better predictor of yarn performance than the traditional test method (20 breaks, approximately 15 meters of yarn).

The clamp distance on the Uster® Tensojet is fixed at 50 cm and the selection of test speed on the current model is 200 or 400 m/min with 400m/min being the standard test speed. Due to its ability of measuring strength at ultra high speeds, it simulates the dynamometric stress of a yarn during the weft insertion process allowing to forecast the weavability of the yarn.

Because of the difference in testing speeds, there will be a difference in strength and elongation results between the Uster® Tensojet and the Uster® Tensorapid; the amount of difference depends upon the fiber type and spinning system and it is caused by the way the yarns physically react when different rates of force are applied to them.

Although the Uster® Tensojet and the Uster® Tensorapid yield different values, the correlation between the two instruments is excellent. It is also important to note that test results will also vary within any instrument if the tests are carried out under different testing parameters (speed, clamp distance, pre-tension, etc).

The reason why somebody would choose a Uster® Tensojet and a Uster® Tensorapid largely depends upon the type of yarn to be tested. The Uster® Tensojet, while extremely fast, is limited in its application range. It was designed to test only staple yarns with a count range of approximately 4/1 to 120/ Ne. and the maximum force and elongation is 50N and 70% respectively. It is not designed to test filament yarns, highly elastic core yarns, or high tenacity performance yarns.

The Uster® Tensorapid is a more versatile machine; it can test staple yarns, performance yarns, highly elastic core yarns, and filament yarns. With specialized clamps, it can also test yarn hank, fabric, sliver, and roving samples. Maximum force and elongation for the Uster® Tensorapid are 1500 N and 1000% respectively. If the yarn to be tested falls outside of the application range of the Uster® Tensojet, or wishes to perform specialized testing, the Uster® Tensorapid would be the better choice.

Besides measuring the characteristics listed in Table 2, there are other parameters measured to contribute to control the consistency of the yarn. There are two types of yarn faults based on the frequency they occur:

- Frequent faults are also called imperfections and can be detected by a yarn evenness tester.
- Seldom-occur faults happen at irregular intervals so tests need to be ran on at least 100 Km of yarn (1000 Km for Open End yarns) in order to obtain a reliable result.

Uster® Classimat is able to detect these faults and classify them in a system based on the fault's length and size, as shown in Figure 2. These data is useful to define and control clearer settings in the winders. The percentages showed as a description of the fault sizes refer to the mean number of fibers in a cross-section of a yarn.

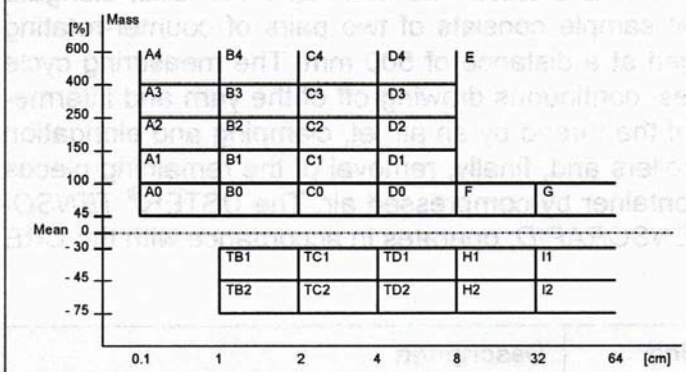
Characteristics	Description		
• Fault classification			
• Fault lengths	A:	shorter than 1 cm	
	B+TB:	1 to 2 cm	
	C+TC:	2 to 4 cm	
	D+TD:	4 to 8 cm	
	E:	longer than 8 cm	
	F+H:	8 to 32 cm	
	G+I:	longer than 32 cm	
• Fault sizes	0:	+45 to +100%	
	1:	+100 to +150%	
	2:	+150 to +250%	
	3:	+250 to +400%	
	4:	over +400%	
	E:	over +100%	
	F+G:	+45 to 100%	
	TB1/TC1/TD1/H1/I1:	-30 to -45%	
	TB2/TC2/TD2/H2/I2:	-45 to -75%	
• Fault channels of the clearers	N channel for very short thick places S channel for short thick places L channel for long thick places T channel for long thin places C channel for count deviations		
		Sensitivity	Reference length
	N channel:	+100% to +500%	
	S channel:	+50% to +300%	1 to 10 cm
	L channel:	+10% to +200%	1 to 200 cm
	T channel:	-10% to -80%	10 to 200 cm
	C channel:	±5% to ±80%	12.8 m

Figure 2. Classing matrix of the Uster ® Classimat. Source Uster ® Application Report.

Based on their constant technological innovation and business strategies, they have been able to set quality standards for fibers and yarns in the textile industry, such as the Uster® Statistics, for example.

Uster® Statistics are a practical guide to good textile practices in the field of yarn manufacturing. The company has compiled yarn quality control information from all over the world and built what can be described as comparative standards. These standards help yarn manufacturers to evaluate their performance and compare it to the average performance of the global industry. At the same time, they are used by yarn consumers as a tool for supplier evaluation and product specification. An example is shown in Figure 3.

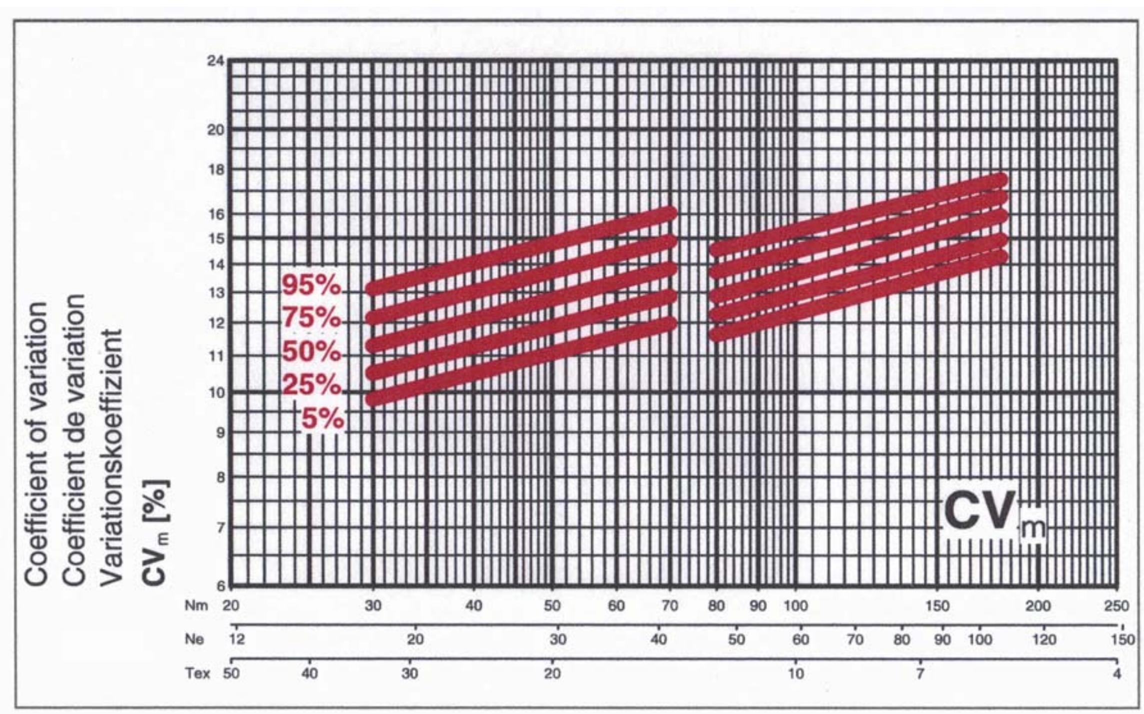


Figure 3. Mass Variation Cotton 100%, combed, ring spun, cone, knitting. Source: Uster® Statistics

Figure 3 can be read as follows: for a 20 Ne yarn, only 5% of the samples (gathered from around the world) have a CV_m of 10%. For this specific example the origin of the yarns tested were 14% North and South America, 9% Europe, 11% Africa and 66% Asia and Oceania

Poor yarn quality can be caused by a deficient quality management system in the mill that do not support product consistence or by failure of the yarn buyers or users to specify precise yarn quality parameters as a function of the end use and the subsequent production processes.

The company has identified that quality costs in the textile value chain represent at least 10% of the final sale value and that companies are increasingly putting more emphasis in the quality assurance of the entire supply chain. Figure 4 from the Uster® Statistics 2007 shows the improvement of yarn evenness between 1957 and 2007.

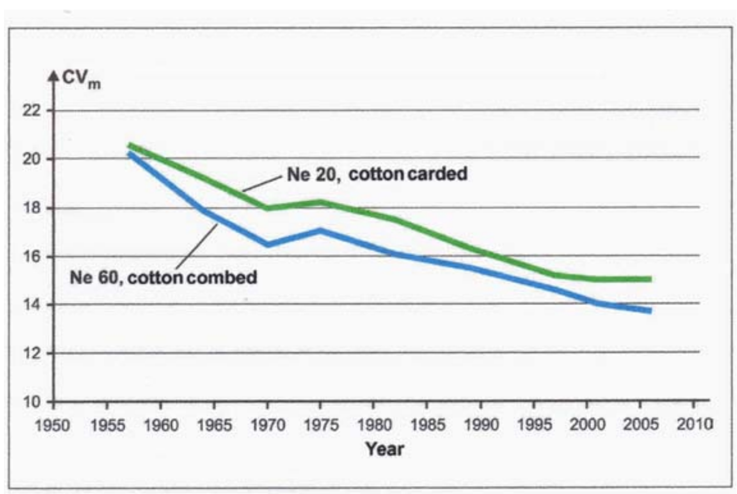


Figure 4. Improvement in yarn evenness between 1975-2007. Source: Uster® Statistics 2007.

Table 6.Agreement on maximum or minimum requirements for different nominal yarn counts of ring spun yarn, 100% cotton, combed for knitting applications. Source: Uster® Application Report SE-601.

Yarn Count and Twist		26 Nec	32 Nec	36 Nec	40 Nec	Uster® Statistics
Deviation of count (%)	Max	+- 2.5	+- 2.5	+- 2.5	+- 2.5	
Count Variation CV_b (%)	Max	1.5	1.5	1.5	1.5	50%
Twist multiplier alpha e	Max	3.6	3.6	3.6	3.6	
Variation of twist CV_t (%)	Max	3	3	3	3	
Direction of twist		Z	Z	Z	Z	
Yarn evenness and hairiness						
Uster eveness CV(%)	Max	11.8	12.5	12.7	12.9	20%
Thin places -40% (1/km)	Max	37	60	91	113	20%
Thin places -50% (1/km)	Max	1	2	2	2	20%
Thick places + 35% (1/km)	Max	182	240	300	340	20%
Thick places + 50% (1/km)	Max	16	19	23	25	20%
Neps + 140% (1/km)	Max	153	200	245	272	20%
Neps + 200% (1/km)	Max	35	45	57	63	20%
Uster hairiness	Max	4.8	4.6	4.4	4.3	50%
Yarn strength and elongation						
Single end strength (cN/tex) conventional	Min	15	15	15	15	95%
Strength variation CV(%) conventional	Max	8.3	8.6	8.8	8.9	75%
Single end elongation (%) conventional	Min	5.2	5	4.9	4.8	75%
Single end strength (cN/tex) high speed	Min	16.5	16.5	16.5	16.5	95%
Strength variation CV(%) high speed	Max	8.6	8.9	9.1	9.3	75%
Single end elongation (%) high speed	Min	4.7	4.6	4.5	4.4	75%
Significant Classimat faults remaining						
A3+B3+C2+D2 cumulative (1/100 km)	Max	14	14	14	14	50%
E (1/100 km)	Max	0	0	0	0	50%
H2 + I2 (1/100 km)	Max	0	0	0	0	50%
Foreign fibers A3+B2+C1+D+E1 cumulative (1/100 km)	Max	0	0	0	0	50%

Uster® has been able to create yarn profile rankings based on Uster® statistics and collaboration of the partners of the company that agreed maximum or minimum requirements for different spun yarns and nominal yarn counts as shown in Table 6 in the previous page.

The percentile value in the last column shows where does a particular yarn quality parameter ranks within a given yarn database. For example with respect to yarn strength, a 95th percentile ranking would indicate that 95% of the yarn samples in the same database as the tested yarn had strength values higher than the tested yarn. Conversely, a 5th percentile ranking with respect to strength would indicate that 95% of the samples in the same database as the tested yarn had strength values lower than the tested yarn. While the 95th percentile may be considered "bad" and the 5th percentile "good", this view is too simplistic. The overriding factor in determining yarn quality is its end use application and this point must be taken into consideration when interpreting the Uster® Statistics.

The standard testing methods apply to Uster® products are:

- ISO 2060 Determination of yarn count. (Uster® Tester)
- ISO 2649 Determination of yarn evenness. (Uster® Tester)
- ISO 2062/ASTM D-1578 Single end tensile test (Uster® Tensorapid)

2.5.2 Other Companies

There are other companies that produce advanced quality control and laboratory testing equipment for sale in the United States, some of them are:

- MESDAN S.p.a - http://www.mesdan.com
- Lawson-Hemphill - http://www.lawsonhemphill.com
- Textechno Herbert Stein GmbH & Co. KG - http://www.textechno.com
- Zweigle Textilprüfmaschinen GmbH & Co. KG - http://www.zweigle.com

2.6. Product Data Management (PDM)

When conceived in the late 1980's, PDM was a design-centered software package used to manage product design data, focusing in engineering and manufacturing, capturing product data from the original release to the data's obsolescence. The main concern was to manage the initial release of data to manufacturing and managing the engineering change order process initiated by manufacturing. Some vendors of this package build the PDM function into the CAD (Computer Aided Design) system software; others use separate software that interface with the CAD system. (Rehg & Kraebber, 2005)

PDM is a computer-based system that helps to manage and control engineering data, engineering activities, engineering changes and product configurations. The system allows many departments of the company to upload and share information generated in their areas and provides support for the activities of product teams and for techniques that aim to improve engineering workflow and engineering process. (Stark, 2000)

PDM systems store and organize CAD (Computer Aided Design) but have also other functions. The most important is to control a coorporation's master ingenieering bill of materials (BOM), which contains all the information of the individual parts and materials used to make the product. . (Rehg & Kraebber, 2005)

As per Stark (2000), the basic components of a PDM system are:

- **Information warehouse** in which engineering information is stored. This information can be description of products and parts such as engineering drawings, CAD data, circuit layouts, flow charts, and test results, bills of materials, field data and word-processed product specifications. It also can be traditional media such as paper, mylar, and aperture cards, or electronic
- **Information management module** to control and manage the information warehouse.
- **Basic infrastructure** of a networked computer environment.
- **Interface module**, to provide interfaces for programs such as CAD and ERP and give to users and other programs.
- **Information structure definition module**, to define the structure of the information to be managed.
- **Workflow structure definition module**. The workflow is made up of a set of activities to which information can be associated; the module defines the structure of the process to be managed.

- **Information structure management module**, to maintain the exact structure of all information in the system.
- **Workflow control module**, to controls and coordinate the engineering process.
- **System administration module**, used to set up and maintain the configuration of the system, and to assign and modify access rights.

PDM systems address the creation, flow, control and use of critical product and process data elements. Figure 5 shows the main role of a PDM system.

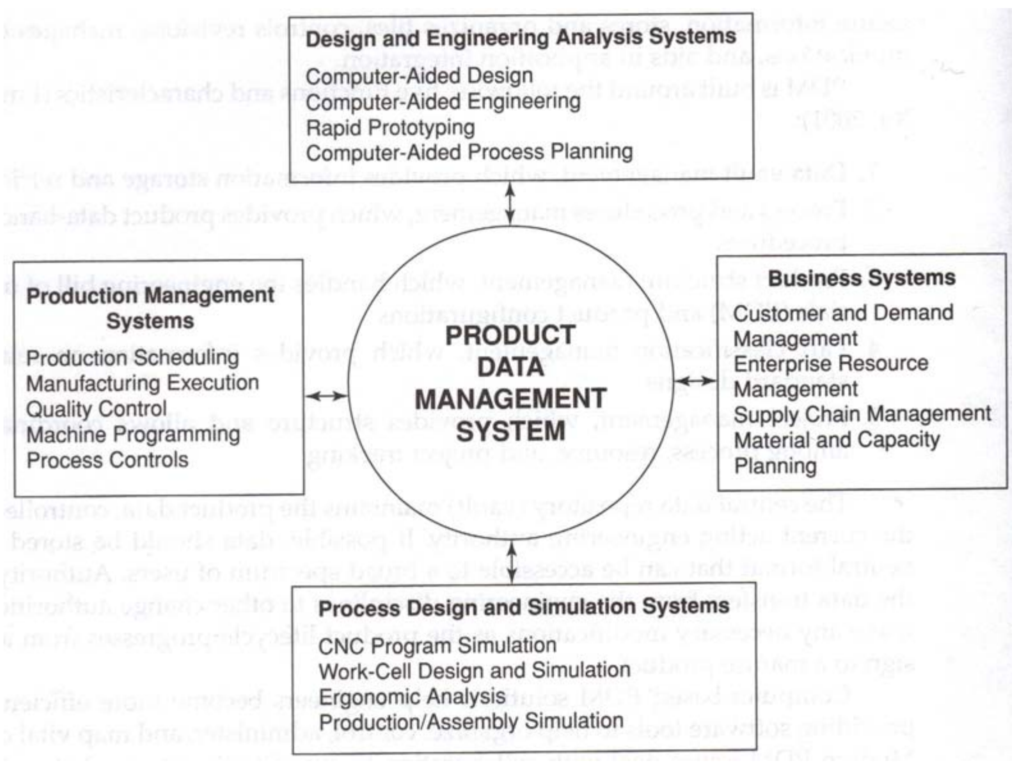


Figure 5. PDM system interface model. Source: Rehg & Kraebber, 2005

2.7. Order Winning Criteria

According to Hill (2005), competitive criteria are divided in to categories, qualifying and order-winning. The qualifying criteria provide the product or service the opportunity to compete in a market; the qualifier factors are those that match the customer's requirements. On the other hand, the order-winning criteria are what make companies win orders against competitors that also qualified to participate in the same market. Both types change within time and from market to market.

A company can develop competitive advantages by linking the qualifiers and order-winner factors to their operations strategies, building the bridge between the technical specifications (dimensions) of the product or service and the business specifications (qualifiers and order-winners).

Examples of relevant qualifiers and order-winners are: price, quality conformance, delivery reliability, delivery speed, product or service variety, innovation, reaction to demand peaks, and other specific customer's needs.

When selecting suppliers qualifiers and order-winners will not be the only considerations to take into account. Hill proposes weighted-factor rating approach, once the selection criteria is agreed, points will be given depending on their level of importance and the each possible supplier will be rated, as shown in Table 7.

Table 7.Weighted-factor rating approach to evaluate suppliers. Source: Hill, 2005.

Factors		Weights	Supplier A	Supplier B
Order-winners and qualifiers	Delivery on time	60	50	60
	Delivery speed	80	40	70
	Quality conformance	40	40	35
	Price	30	30	20
	Technical support	40	30	35
	SUBTOTAL	250	190	220
Operations	Current capacity	20	20	20
	Ability to increase capacity in the short term	10	0	10
	Meet mid-term growth requirements	50	30	45
	SUBTOTAL	80	190	220
Technical	Level of technical staff provision	50	40	45
	Staff technical know-how	30	25	30
	Future contributions to developing products and services	20	10	15
	SUBTOTAL	100	75	90
Corporate	Managerial and financial standing of the organization	70	50	60
	SUBTOTAL	70	50	60
TOTAL		**500**	**365**	**445**

Rehg & Kraebber (2005) presents Terry Hill's model with the winning-order criteria as the common language linking both marketing and manufacturing areas. Figure 6 shows the five steps of planning process, the model promotes debate about how the established manufacturing strategies allow the company to produce the products demanded by the market place. The order-winning criteria provide the vocabulary to describe the product market requirements and translate them into process choices and infrastructure requisites by manufacturing.

Corporate goals	Marketing strategy	Manufacturing order-winning criteria	Manufacturing strategies: Structure	Manufacturing strategies: Infrastructure
What the company is going to do: • Growth • Profit margin • Other financial measures	How the company will reach desired goals: • Product markets and segments • Mix • Volumes • Standardization versus customization • Level of innovation • Leader versus follower	• Price • Quality • Lead time • Delivery/reliability • Flexibility • Innovation ability • Size • Design leadership	• Capacity • Facilities • Technology (processes used) • Vertical integration (degree to which all parts are produced internally)	• Workforce (pay, skill level) • Quality achievement process • Manufacturing planning and control system • Organization (control, measurement, motivation)
External focus		*Common language*	*Internal focus*	

Figure 6. Order-Winning Criteria Model. Source: Rehg & Kraebber 2005.

Most of the criteria listed in the third column of figure 6, must be addressed by the manufacturing area, therefore they need to now the standards and performance metrics necessary to compare their performance to their competitor's and to evaluate if they are ready to provide the order-winning criteria. Rehg & Kraebber (2005)

2.8. Performance Metrics

Performance measurement is defined by Hatry (2006) as regular measurement of the results (outcomes) and efficiency of services or programs. Regular measurement of the progress achieving an objective is a key component of managing by results. Performance information establishes accountability, budget proposals justifications, and resources' utilization levels.

A performance measurement is the process of quantifying the efficiency and effectiveness of an action, where measurement is the process of quantification and action leads to performance. A performance measure, then, is the metric used to quantify the efficiency and effectiveness of an action and a set of them make the performance measurement system. Performance measures need to be aligned with the strategies of the company, since they are able to influence what people do. (Neely, et al., 2005)

Figure 7, explains graphically the role of a performance measurement as a control tool between he inputs and the outputs of an operations process.

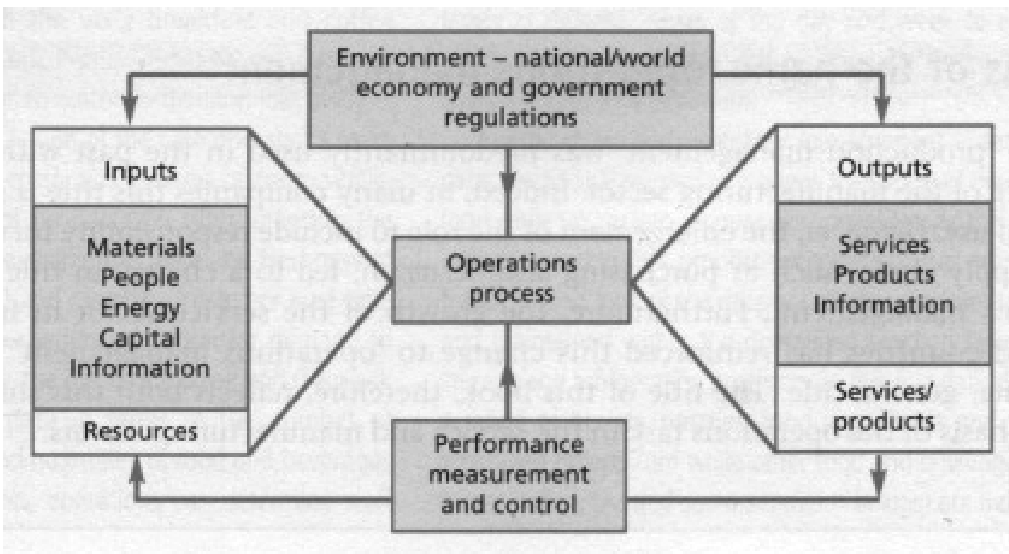


Figure 7. The role of performance measurement in the operations process. Source: Hill, 2005.

The key dimensions of manufacturing's performance are quality, delivery speed, delivery reliability, price/cost, and flexibility. Quality related measures do not only refer to the conformance to specifications of a product, with the development of the Total Quality Management (TQM) philosophy customer satisfaction concepts have been included under this dimension. Just in Time (JIT), Optimized Production Technology (OPT, minimization of throughput times) and ABC Costing System are tools that help to define what would be the best measures to apply for delivery speed, delivery reliability and price/cost dimensions. As per the flexibility dimension, operational measures should be taken into account; this includes modification flexibility (design changes made in a component in a finite time), re-routing, and volume and material flexibility.(Hill, 2005)

An empirical study of performance measurement in manufacturing firms was conducted by Gosselin (2005), showing that despite the suggestions made in literature, manufacturing companies still put more emphasis on financial measures when designing their performance measurement system, rather than incorporate non-financial measures. A list of the seventy-three performance measurements used to conduct this study can be found in Appendix C

Net profit, gross profit margin, total sales department, amount of raw material inventory, cost per unit produce and others represented the first eleven measures mentioned by the companies that participated in Gosselin's study. The first non-financial measure was the number of worker injuries in twelfth place.

Gosselin's study conclusions were that the performance metrics most commonly used in companies are usually the same, even if the company has balance score cards or integrated performance metrics systems. Companies where the decision-making process pertaining to the management of divisions is decentralized tend to use more non-financial measures than centralized organizations.

Those companies in an unstable environment would tend to use financial measures but also non-financial measures related to customers and employees.

Finally, Gosselin's study concludes that companies defined as prospectors, very dynamic looking for market opportunities, capable of large investment in research and development areas; tend to put more emphasis in non-financial measures related to customers, products, employees and quality. Companies defined as defenders, operate in narrow product-market domain, producing high volumes and low product variety; use financial measures more frequently.

2.8.1 Balance Scorecard

Graham (2000) defines a company's scorecard as a collection of performance measures that provide information on performance, and describes several models to create a scorecard. Kaplan and Norton's Balance Scorecard Model includes four categories of data: customer measures, financial measures, internal measures and innovation/growth measures. The internal measures include productivity, efficiency, internal quality, industry-specific metrics, supplier partner performance, etc.

Graham also mentions the Baldrige Award Model, including customer-focused results, financial and markets results, human resource results, supplier and partner results and organizational effectiveness results. This model is good for organizations that are labor-intensive and spend a lot of money in on outside suppliers and contractors.

Dicover Financial Services Scorecard, The Scorecard Structure of a Leading Securities Firm, and the Military Scorecard Designs are other examples of models used to build scorecards. Whatever are the metrics the company decided to use, they need to be linked to the company's overall goals. Measures are based in two types of metrics: counting (which are more objective and less time consuming) and judgment (rating, ranking, specific criteria and opinions).

2.8.2 Supplier Appraisal

Emmett & Crocker (2006), define supplier appraisal as the action of selecting and measuring suppliers in order to asses those more suitable for potential long-term collaboration. The approval criteria used by procurement departments include:

- Technical competence.
- Managerial competence (how well run is the company)
- Financial stability.
- Reliability.

Supplier performance can be measured by comparing it to:

- A standard.
- Performance on a previous order.
- Another's supplier performance.

To insure continuous improvement of a supplier, it is necessary to control or audit its ongoing performance. In a collaborative relationship, these audits should identify areas for improvement for mutual benefit, rather than a tool to find faults that provide a negotiation lever.

2.9. Literature Review Conclusions

The literature reviewed concerning the status of the U.S. textile and apparel industry in regards of cotton yarn manufacturing and final products selected for this research showed that domestic industry is highly affected by imports from Asia and Central America, that has caused a considerable shrinkage of the textile and apparel industry in the U.S. and has forced companies to either shut down operations or initiate operations in neighbor countries taking advantage of trade agreements.

Information about standard testing methods and standardization organizations was found and revealed that although there are specific testing methods and equipment to measure yarn characteristics, there are a few sources that set standard specifications or values for each yarn characteristic. The reason might be there is a considerable amount of fabric qualities that can be obtained by changing one simple yarn characteristic and at the end when trying to establish the characteristics that define a "good yarn" the answer will be "It all depends of the type of final product…"

The majority of Product Data Management systems focused on the management of data of complex products, with many components, it was not possible to identify examples of applications for yarns, maybe due to their simple data structure.

Finally, it was possible to identify and define the performance metrics and winning-order criteria that will help to develop the following chapters.

3 METHODOLOGY

3.1. Theory Building Process

To obtain in depth knowledge of the dynamics and business practices of the actual textile and apparel industry that will allow us to accomplish the objectives of the present research, information needs to be collected from all the different components of the supply chain. The purpose of building a theory based on the information collected during the research is to make it useful and applicable in the future.

According to Handfield and Melnyk (1998), theory is the vehicle that links data to knowledge; without theory, empirical research merely becomes "data-dredging"; therefore the theory-building process serves to differentiate science from common sense. Figure 8 shows a map of the stages that usually occur in the scientific process.

The three pillars on which science is built are: observation, induction and deduction. Observations are specific and unique items of information; they can become empirical generalizations by performing measurements, sample summarization and parameter estimations. Empirical generalizations in turn, can become theories via concept formation, proposition formation and proposition arrangement. A theory is a more general type of information that after applying logical deduction is transformed into hypotheses. These hypotheses become new observations via interpretation, instrumentation, scaling and sampling. These new observations will become empirical generalizations again and the hypotheses they came from may then be tested for conformity to them. The results of the testing will be a decision that either accept or reject the truth of the hypotheses. Once again by logical deduction the theory will be confirmed, modified or rejected.

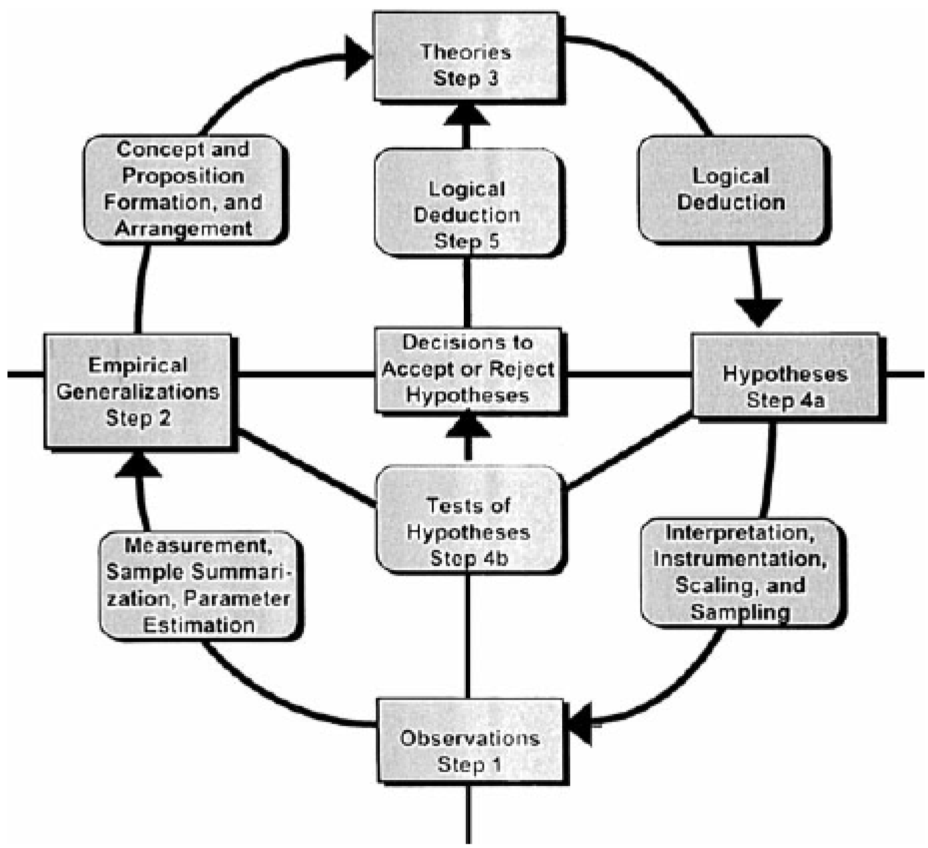


Figure 8. Principal information components, methodological controls and information transformations of the scientific process. Source: The Logic of Science in Sociology by Wallace, 1971 (as cited in Handfield & Melnyk ,1998)

3.2. Case Study and Survey Methodologies

After reviewing available research methodology literature and studying examples of Case Study and Survey research in the areas of in Operations Management and Supply Chain

Management, it was found that they can be used as complementary tools to conduct a research of exploratory nature as the present one.

Case Study research methodology allows flexibility of data collection and the chance to validate it by triangulating information obtained at different links of the supply chain. It is also useful to map the field been investigated and to identify and describe the critical variables (Seuring, 2005).

A case study is an empirical methodology that typically uses multiple methods and tools for data collection from a number of entities by a direct observer in a single, natural setting that considers temporal and contextual aspects of the contemporary phenomenon under study, but without experimental controls or manipulations. The methods and tools employed include both quantitative and qualitative approaches: financial data, interviews, memoranda, questionnaires, organization charts, etc. (Meredith, 1998)

On the other hand, survey research involves the collection of information from individuals (through mailed questionnaires, telephone calls, interviews, etc.) about themselves or about the social unit to which they belong by using a structured format. Survey research is usually a quantitative method that requires standardized information in order to define or describe variables, or to study relationships between variables. The information is gathered via a sample, which is a fraction of the population. (Gimenez, 2005)

Case studies and surveys differ in the research purpose for which they are normally used. Case studies are appropriate for exploring new areas of research, identifying key variables or linkages between variables and generating hypotheses (theory building), because they provide the type of knowledge that cannot be gathered purely from the statistical analysis formatted questionnaires. Surveys instead are a very useful in the "hypotheses testing" stage of theories developed in the previous stages of research. For these reason, they can be considered as complementary tools. (Gimenez, 2005)

Forza (2002) explains in detail all the necessary steps and considerations to carry out a survey research; Voss,Tsikriktsis and Frohlich (2002) did the same but for case study research. Although both methodologies are complementary, but due to the number of companies that will be contacted in the time frame for this research, it has been decided to apply only case study research methodology, which still gives the opportunity to propose hypotheses and test them. The sequence of steps to follow is show in Figure 9.

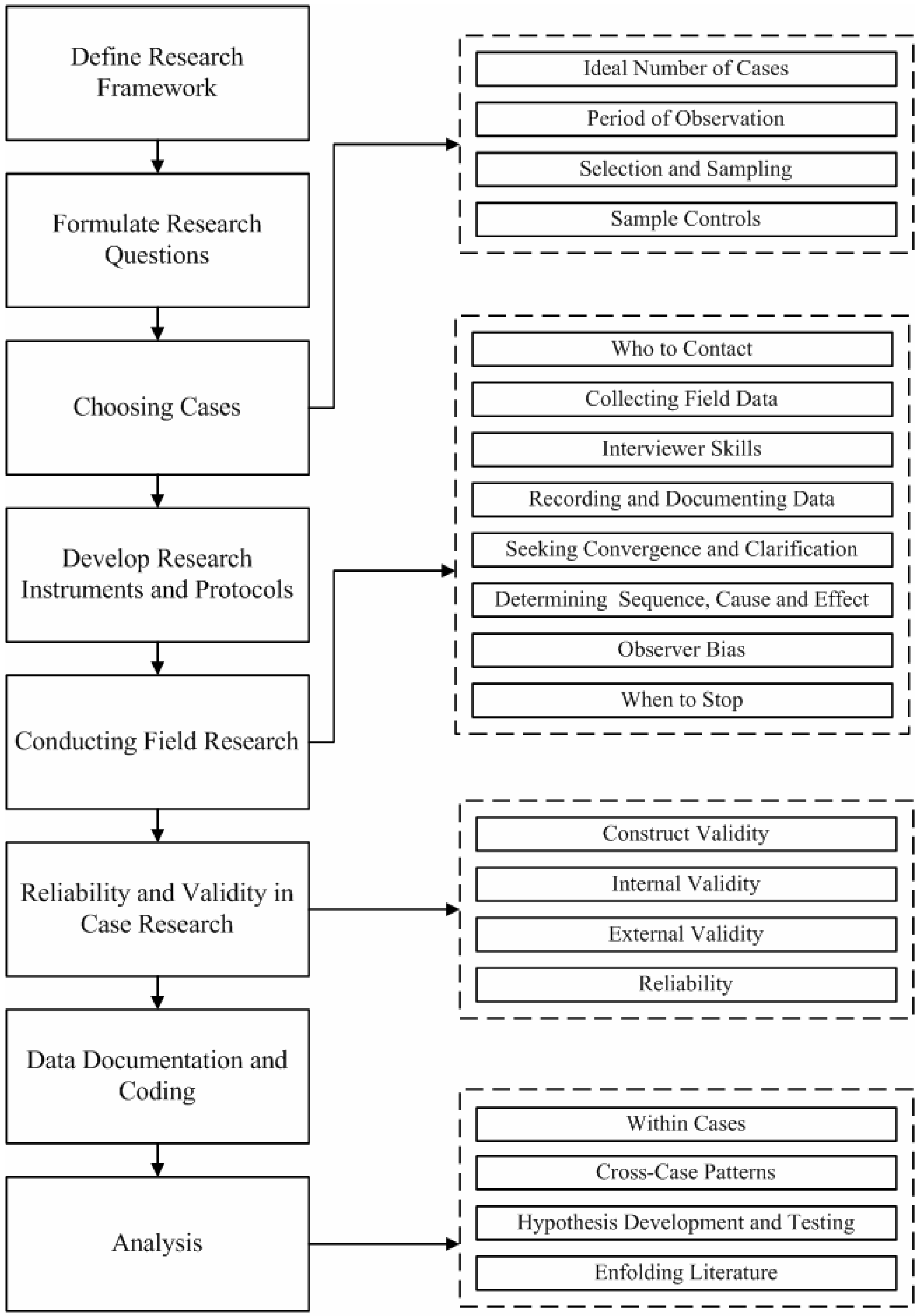


Figure 9. Case Research Scheme. Source: Based on Voss,Tsikriktsis and Frohlich (2002).

3.3. Application of Case Study Methodology

This section describes the steps taken to conduct this research based on the case study methodology proposed by Voss,Tsikriktsis and Frohlich (2002).

3.3.1 Research Framework

This research was developed under the framework given by the U.S. textile and apparel supply chain. It was desired to identify what are the relationships that yarn manufacturers and the other components of the supply chain maintain and also determine how big is the lack of communication that keeps yarn manufacturers far removed from the retailers, and what are the variables that describe these dynamics.

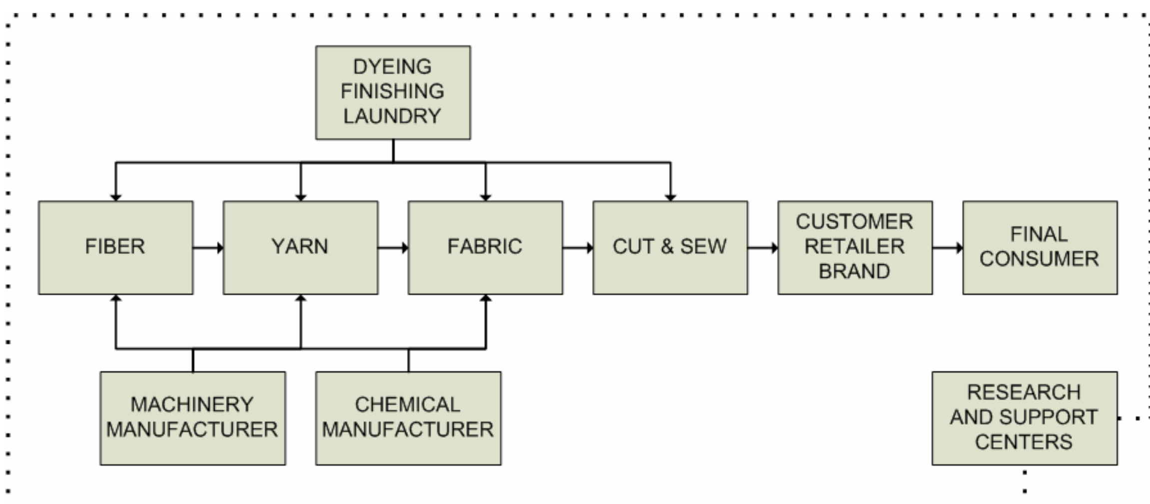


Figure 10. Textile and Apparel Supply Chain.

By mapping the specification process across the supply chain and understanding the actual business practices it was possible to identify what are the characteristics of the yarns and the services that domestic yarn manufacturers should be providing in order to differentiate their products from offshore sources and remain competitive.

3.3.2 Research Questions (Objectives)

Domestic yarn manufacturers must address the requirements of all the participants in the textile and apparel supply chain in order to remain competitive and to differentiate their products from offshore sources. The objective of this research was to better understand these requirements through visits to companies, elaboration of case studies, discussions and interviews with members of the supply chain.

Previous researches related to the competitiveness of U.S. textile and apparel industry approached the problem from a business, marketing and supply chain point of view. (Allen, 2006; Berdine, 2007; Nowell, 2005; Cesca, 2005). In order to contribute to the competitiveness of the U.S. textile and apparel industry, this research focused in two specific areas within the supply chain: the yarn specification process and the performance metrics used across the supply chain.

After defining the research framework and the results desired to be obtained from the research, the following objectives were formulated:

- RO1. Map the yarn specification process across the supply chain.
- RO2. Identify yarn specifications considered important to yarn manufacturers, yarn buyers and other participants of the supply chain.
- RO3. Identify current standard testing methods and equipment used to evaluate yarn properties.
- RO4. Identify the most important yarn specifications as a function of the final product.
- RO5. Identify performance metrics used by yarn manufacturers, yarn buyers and other participants of the supply chain.
- RO6. Define "order qualifying and order winning criteria" for domestic yarn manufacturers that will allow them to remain competitive and differentiate their products from offshore sources.
- RO7. Evaluate existing product data management systems as to how they incorporate yarn characteristics into designing the final product.

3.3.3 Choosing Cases

In order to guaranty the validity of the results and to avoid observer bias, companies from most of the links of the supply chain were contacted. The main sources used included:

- Company members of the Institute of Textile Technology.
- Textile Connect directory: http://www.textileconnect.com
- Cotton Inc. directories:

- http://www.cottoninc.com/EFS/EFSSourcingDirectory/index.cfm?p=yarn
- http://www.cottoninc.com/EFS/EFSSourcingDirectory/index.cfm?p=fabric
- Cotton U.S. Sourcing Program: www.cottonusasourcing.com
- Davison's Textile Blue Book: http://www.textilebluebook.net
- Honduran Manufacturers Association

The selection of the companies was made based on the type of products they produce or commercialize. Yarn manufacturers producing cotton and poly-cotton yarns were selected; as well as manufacturers producing sewing thread, socks, and fabrics for jeans, t-shirts, and sheets all made of cotton and poly-cotton blends. Garment manufacturing and retailers producing and commercializing the products described were also included.

It was desired to incorporate in the sample companies that were in the same category but aiming different markets. For example, a yarn manufacturer producing specialty yarns and another producing commodity yarns. The purpose was to obtain disconfirming and exceptional information that will cover different business practices. The same selection criteria were applied for the retailers. Regarding the cut and sew companies, they were contacted after talking to the retailers and researching directories to see if the ones chosen where supplying to the retailers interviewed.

The geographical location of the companies was also considered during the selection; giving priority to the ones located in North Carolina, South Carolina and Georgia, in order to make easier the collection of data. It was necessary to conduct interviews by phone due to the location of the retailers and the cut and sew companies.

3.3.4 Developing Research Instruments and Protocols

In case study research, the most common instruments to obtain data are structured interviews, personal observation, informal conversations, attendance to conferences, surveys and review of archival sources. Protocols include the instruments, procedures and rules necessary to conduct the cases and also indicate where the information needs to be sought. Voss,Tsikriktsis and Frohlich (2002).

Interviews were the instrument selected to gather data; a copy of the set of questions that were used as guideline to conduct them can be found in Appendix D. All the questions applied to yarn and fabric manufacturers. Some of them had to be ignored or modified when interviewing other participants of the supply chain, and these modifications were taking into account when analyzing the data.

Special care was put when wording the questions of the questionnaire so that the information obtained were consistent with the respondent's level of understanding, not all the interviewees were experts in yarn manufacturing. The correct formulation of the questions can avoid getting unreliable and biased responses due to the lack of understanding or misinterpretation.

The questionnaire contained open-ended questions (allows answering in any way chosen) and closed question (limiting respondents to a choice among given alternatives). Once formulated, a reiterative process of revisions and modifications occurred until professors and industry people approved the final version of the questionnaire as the definitive to be used in the interviews.

As per the protocol, the first approach to the selected companies was made by e-mail, giving a brief explanation of the purpose and objectives of the research, as well as information about the researcher and the university; it was believed that this could increase the confidence of the interviewees on the project and obtain a higher response rate. After the first try by e-mail, phone calls were made to confirm if the e-mail was received and to set an appointment in case they wanted to participate in the research.

3.3.5 Conducting Field Research

As per the theory-building process presented by Handfield and Melnyk (1998), theory is the vehicle that links data to knowledge; without theory, empirical research merely becomes “data-dredging”; therefore the theory-building process serves to differentiate science from common sense. Therefore the field research was conducted in two stages, the first one to make the observations and not necessarily create hypothesis, but define the dynamics of the textile and apparel supply chain and the yarn specification process. The interviews conducted in the second stage helped to confirm the findings of the first stage.

Face to face interviews were conducted seeking out the person or group of persons who were most knowledgeable about the areas researched. Usually the first person to be contacted was the CEO or the manager of an area because they could open the doors within the organization, provide enough support for the research and know who else to get involved. Ideally a person representing one of the following areas participated: Merchandising, Sourcing, Production, Quality Control, Product Development or Design.

In some cases interviews needed to be conducted by phone using the same guideline shown in Appendix D.

As mentioned before, the interviews were conducted in two phases. In the first one, the exploratory stage, sixteen companies/research organizations were interviewed to:

- Identify and define the variables to be studied.
- Postulate relationships amongst those variables.
- Justify the reasons why were those relationships presumed.
- Define the conditions or environment in which those relationships develop.

Phase two included another group of sixteen companies/research organizations, but this time focusing in yarn manufacturers and fabric manufacturers, links where the yarn specifications play a more important role.

3.3.6 Reliability and Validity in Case Research

The reliability and validity of the tools and procedures used to conduct the research were evaluated after the interviews were conducted, keeping in mind that they should accomplish the following requirements, explained by Voss,Tsikriktsis and Frohlich (2002).

Construct validity represents how adequate are the operational measurements selected for the concepts being studied. Construct validity can be tested by:

- Observing whether predictions made about relationships to other variables are confirmed.
- Using multiple sources of evidence, (similar results are evidence of convergent validity).
- Seeing if a construct as measured can be differentiated from another, (evidence of discriminant validity).
- Seeking triangulation that might strengthen construct validity.

Internal validity was dictated by how well can a casual relationship can be establish, and by which certain conditions are shown to lead to other conditions, as distinguished from false relationships. The key to establish internal validity is to understand what the theoretical relationship is and why it happens and qualitative data often provides the answers. Multiple cases have higher external validity than single cases.

External validity means whether the findings of a study can be generalized beyond the immediate case study.

Reliability is the degree of confidence in obtaining the same results if the study is repeated following the methodology use to conduct it.

3.3.7 Documentation and Coding

As part of the protocol, interviews were writing up as soon as possible after they were conducted to maximize recall and facilitate follow-up and filling of gaps in the data. The questions used as guidelines were formulated based on the research objectives. Therefore, the answers obtained were grouped based on the objectives they covered. By comparing each group with previous observations in the same category, it was possible to identify concepts, relationships, trends and measures for future analysis.

3.3.8 Analysis

Initially, case studies were analyzed individually looking for answers to accomplish the objectives and highlighting exceptional practices, understanding their role within the supply chain and capturing the point of view of the company regarding yarn specifications.

Then companies were group according to the link of the supply chain that they belonged to, comparing them to find similarities or differences within the group. Then an analysis between groups was made, looking for a pattern, explanation and causality, and to draw valid conclusions from it.

The second phase of interviews was conducted to verify the assumptions made based on the results of the first phase.

4 RESULTS AND DISCUSSION

Case studies were conducted with the participation of machinery, yarn, fabric and apparel manufacturers, as well as research and retail organizations. Both domestic and Latin American companies were pursued; a total of 32 company interviews were conducted involving 64 participants. The products investigated were denim, t-shirts, socks, sheets and sewing thread made of cotton or poly-cotton blends.

Figure 11 shows the number of companies interviewed at each link of the textile and apparel supply chain and Table 8 provides information about the interviewees and their main activities.

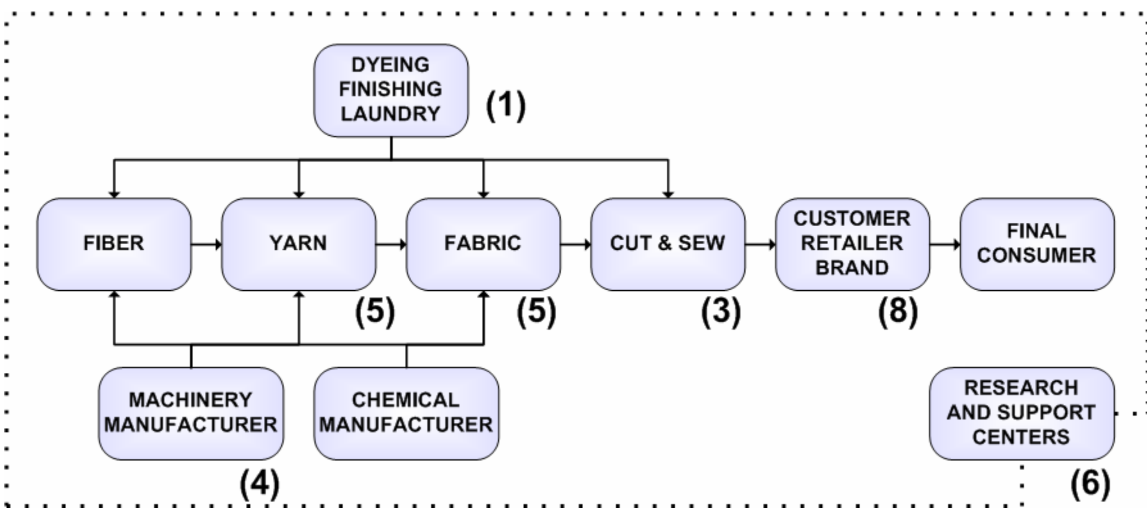


Figure 11. Number of interviews in each link of the Textile and apparel supply chain.

Table 8. Description of companies selected for the case studies.

Machinery Manufacturers	Description
MM1	Manufacturer of fiber preparation, carding and drawing equipment.
MM2	Manufacturer of weaving machines and accessories, winders for spinning, electronic boards, full fashion and technical textiles knitting machines.
MM3	Manufacturer of novel spinning technology.
MM4	Manufacturer of electronics for quality control for the textile industry.
Yarn Manufacturers	**Description**
YM1	Manufacturers of fine-count, combed yarns made from extra long staple cotton. They use exclusively American Supima®-Cotton. Their yarns are sold in 15 countries, mainly in NAFTA-countries, Central- and South America and Singapore. They aim a high end, specialty market.
YM2	One of the largest yarn manufacturers in the U.S. They produce cotton, polyester and blends spun yarns for weaving, knitting, hosiery, industrial, military and home furnishing markets. They have manage do develop manufacturing processes and engineer yarns that allow them to produce the widest range of yarn counts in the market and specialty fibers.
YM3	Producers of ring spun specialty yarns. Combed cotton heather yarns remain the significant product; however they also offer novelty yarns and yarns of various fibers, including rayon and polyester.
YM4	Producers of cotton, synthetic and blended yarns manufactured both in ring, and open-end spinning systems. Plied yarns are available in the full count range and in both spinning types. Slub yarns, nub yarns and core spun yarns are also available.
YM5	Producers of long staple worsted, short staple open end, short staple and air-jet spun yarns. They are especially known for their dyed acrylic yarns, but they can also spin yarns and blends made from polyester, rayon, wool, and specialty performance fibers. The person contacted had previous experiences in cotton yarns manufacturing.
Fabric Manufacturers	**Description**
FM1	Leading supplier of denim to top denim apparel brands. Operates in the US, Mexico, Turkey and India. Expansion initiatives are underway in Central America and China to provide broader service and flexibility to customers worldwide.

Table 8 (continued)	
FM2	Textile manufacturer of woven cotton, poly/cotton, polyester and various blended greige goods.
FM3	Textile manufacturing company. Dobby and plain woven greige fabrics for apparel, furnishing and industrial applications, from cotton and poly-cotton blends.
FM4	Contract knitter.
FM5	One of the world's largest manufacturers of thread and yarns for apparel, non apparel, embroidery, and technical textile applications as well as for the consumer distributor market. Their manufacturing and service centers are located within 50 countries. Although they are embroidery thread manufacturers, they were placed in this category because their products are intermediate products, used to make the products selected for the research.
Cut and Sew	Description
CS1	Bolivian vertically integrated company, from yarn to garment. Offering apparel full package services for knit products for U.S., Argentinean, Brazilian and Spanish retailers.
CS2	Honduran vertically integrated company, from fabric to garment. Offering apparel full package services for knit products for U.S retailers.
CS3	Mexican vertically integrated company, from yarn to garment. Offering apparel full package services for knit and woven products for their own brands and U.S. retailers.
Finishing & Dyeing	Description
FF1	Small lots color development, dyeing and finishing services, including full package custom color standards. Wet finish development (enzymes, stones, bleaching, softeners), garment dyeing and finishing techniques.
Retailers	Description
RR1	Company whose wholesale and retailer business consists of the design, sourcing, marketing and distribution of their collection brands and also has licensing business of product, international and home licensing activities.
RR2	Specialty retailer of casual apparel for men, women, and kids. Its stores offer casual sportswear apparel, including knits and wovens as well as personal care products and accessories. They operate stores in the United States, Canada, and the United Kingdom. Also sells its products through Web-based stores, as well as through a catalogue.

Table 8 (continued)	
RR3	Retailer that operates across the country specialized in an extensive collection of bras, panties, sleepwear, hosiery and more. The catalog and direct (.com) division reaches more than 390 million customers each year through their web site, which is one of the fastest growing and profitable e-commerce destinations on the Internet.
RR4	Consultant and free lance to apparel industry with years of experience in pre-production technical design issues, training in garment fit and sizing, pattern drafting and grading, client-factory liaison and factory review.
RR5	Apparel agent for retailers RR1 and RR2 of this group.
RR6	One of the world's largest specialty retailers. They operate four of the most recognized apparel brands in the world. They consume 1% of the world's cotton crops.
RR7	Direct merchant work directly with mills and manufacturers, eliminating the markups of middlemen. Their products are traditionally styled clothing for the family, soft luggage, and products for the home. They offer products through catalogs, on the Internet and in their Inlet stores.
RR8	Retailer that operates in the United States and Puerto Rico, one of the largest apparel and home furnishing sites on the Internet, and the nation's largest general merchandise catalog business in 2007.
Research & Development Centers	Description
RS1	Research organization focused to promote cotton applications. From agricultural, fiber and textile research, market information and technical services, to advertising and public relations, fashion forecasts and retail promotions.
RS2	World's leading not-for-profit professional association for the textile design, materials, processing, and testing industries. Promotes application of colorants, chemicals, and polymers in the Textile Industry.
RS3	A recognized provider of solutions for the sewn products and related soft goods industries specializing in technology development and supply chain improvement
RS4	Research organization assisting the hosiery industry to compete in a global environment through training, R & D, testing, E-commerce and new product development.

Table 8 (continued)	
RS5	Research organization that offers centralized technical support , helps textile companies to remain competitive, manufacture quality products, and maintain a well-trained workforce by providing testing services, product prototyping, and sample production in several areas.
RS6	Company that delivers technology solutions to the textile industry and is committed to provide software and services that enable customers to save money by streamlining their R&D processes and make money by bringing better products to market faster.

The information collected during the interviews as well as the corresponding analyses are presented in this chapter in the following five sections:

Yarn Specification Process: describes the interaction between the links composing the supply chain, the steps taken and considerations made at each link regarding product specification and identifies the stage where yarn specifications are generated. The questions of the questionnaire in Appendix D that apply to this section are: 1,2,7,10 and 11.

- **Yarn Specifications and Standard Testing Methods**: summarizes the yarn specifications most frequently used across the supply chain, the application and importance given to them at each link, and the equipment and standard methods used to test them. It also provides the most important yarn specifications to be considered as a function of the type of product and its final use. The results and the analysis presented in this section correspond to the answers obtained for questions 3 to 12 of the questionnaire.

- **Order Winning Criteria and Performance Metrics**: identifies what are the criteria used to select suppliers, what are the performance metrics used to evaluate them and how can they be used for product differentiation purposes. Questions 13, 14,15,16 and 17 applied to this section.

- **Product Data Management**: identifies the software and tools available across the supply chain to manage product data, and shows how they incorporate yarn characteristics into the design of the final product. Questions 11 and 12 are related to this section.

- **Business Practices**: is a summary of examples discussed with yarn manufacturers and feedback from fabrication and retail levels, about practices which appear to drive success for yarn manufacturers and bring them closer to the retailers.

4.1. Yarn Specification Process

The product specification process starts at the retailer's end. Six retailers, one agent and one apparel consultant (n=8) were interviewed. Four of them described their procedures to define what are the styles selected for a specific season, how are the fabrics and colors selected, their product development process an how they go from the design to the productions stage.

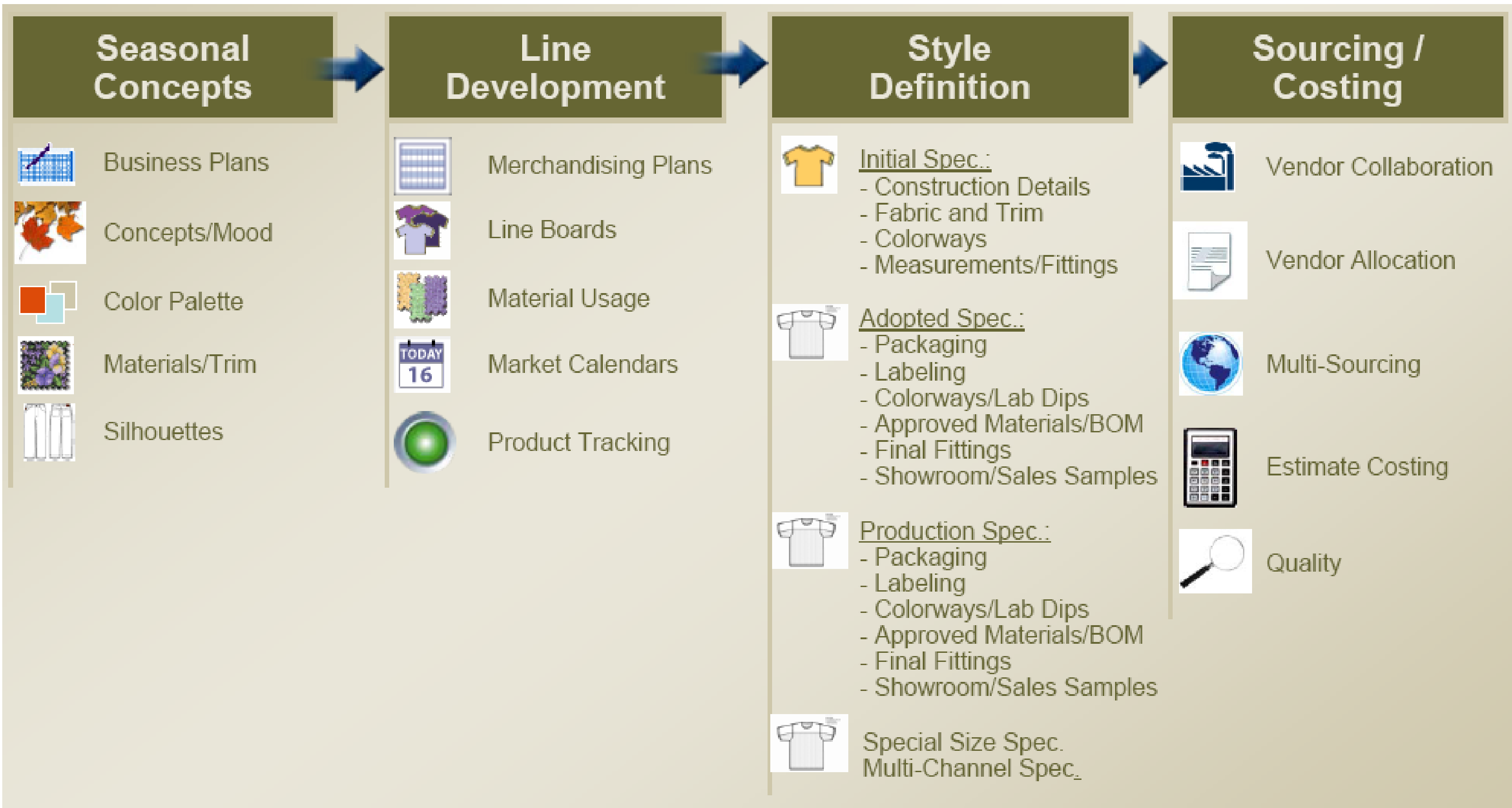


Figure 12. Retailer's Product Specification Process. Source: Courtesy Parametric Technology Corporation (www.ptc.com)

In order to control the design, product development and production stages, these companies use specialized product data management (PDM) or product lifecycle management software (PLM). Conversations with a supplier of a fifth retailer interviewed, confirmed that this retailer uses PDM software too.

There are many software companies offering PLM and PDM packages for the apparel industry, Apparel Magazine published in May 2007 a complete report ranking different PLM/Product Development software providers. Parametric Technology Corporation (PTC) is one of the companies offering PLM software, Figure 12 shows the sequence of the steps taken into account when developing an apparel product and matches the description of the process explained by the four retailers.

Business plans are formulated at the seasonal concept stage considering brand placement, target markets, financial goals, sales and production strategies, government and trade regulations. Within this framework, designers, merchandisers and product development teams will research and identify the concepts, colors, materials and silhouettes necessary to support the business plans.

For this research, designers attend yarn and fabric trade shows to identify trends. Retailer RR2 not only sends their associates to the shows but also promote visits to the mills of their suppliers for designers and product development teams, they even invite mills to show their products and this way RR2 can identify new fabrications and on site developments.

The line development stage is where specific actions are taken to accomplish the business plans. Merchandising plans will bring specific numbers for sale price, production volumes and cost, demand forecasts, etc.

Systems to track the products at subsequent stages will be designed to accomplish the goals in a defined timeframe. The styles to conform a fashion line will be selected as well as the materials they will be made of. Fabric and yarn findings of the design and product development teams are brought together to prioritized and defined core fabrics, their specific attributes and esthetics so that the product development team has clear interpretation of the designer's wishes.

Figure 13 shows the fabric characteristics that designers evaluate when selecting fabrics. The results were gathered from the interviews conducted at the retailer stage (n=8).

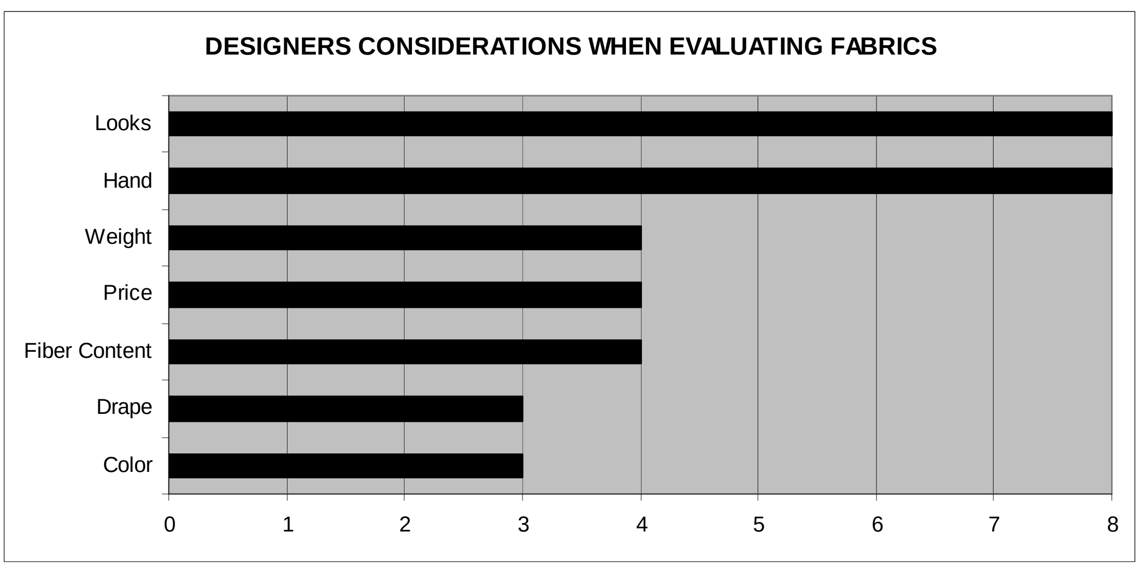


Figure 13. Fabric characteristics consider by designers when selecting fabrics.

More specific fabric and yarn characteristics start being defined at the style definition and sourcing/costing stages, where an iterative process of sample submits between the retailer and the vendors, as well as comments and modifications occur previous to the final approval for production regarding product looks, construction, fabrics, trims, colors, measurements, fit, labels and packing. This approval process was also described by the cut and sew companies interviewed (CS1, CS2, CS3). Sourcing, merchandising and product development teams discuss key vendors for specific allocation of fabric development and production.

The product development teams of the six retailers interviewed communicate the product specifications to their vendors or suppliers, by means of a document called tech. pack. An example of fabric and sewing thread specifications for a jersey t-shirt is shown in Figure 14, provided by retailer RR2. Retailers RR1, RR2 and RR3, have similar technical packages because all three use the same PDM software. In this example the selected fabric was developed and approved in a previous season and pulled from the company's records to be used in the present season, therefore the yarn characteristics specified are: yarn count, fiber content and yarn type (spinning system).

Ideally, when a new fabric needs to be developed, a swatch and a specification sheet are sent to the garment suppliers known also as vendor or CMT companies (Cut-Make-Trim). Three CMT companies were interviewed; all three located outside the U.S. supplying to some of the retailers previously mentioned and all three vertically integrated (CS1, CS2 and CS3).

Two of them manufacture from the yarn to the final product, the third one buys yarn from U.S. manufacturers to make their own fabric, cut and sew it. Vendors CS1 and CS2 commented that most of the time, they will get a fabric swatch only. Figure 15, is an example of a fabric specification sheet, it was provided by vendor CS1.

Once the technical packages are completed, and the merchandisers have decided the price they are willing to pay per garment and how many they want to produce; the sourcing department will send this information to either their agents or directly to their key vendors to obtain quotes. Four of the retailers interviewed contact the vendors directly and the other two through agents (RR1 and RR2).

Retailers refer as an agent: to the company that acts as a mediator between them and the vendor. Vendor: is the company in charge of manufacturing the garments and mills: are the factories manufacturing fabrics or yarns.

The retailers that use agents' services (RR1 and RR2) indicated that it makes it easier for them to obtain the goods so they can focus on design, brand management and merchandising areas, and that agents have better structured supply chains. The retailer will buy the garments from the agent and the agent is responsible for quality and delivery issues. Agents do not own the production either, the receive a commission from the vendor and make money selling the garments to the retailers, so whenever they are charged back they just charge back the vendor.

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Product Development

Fabric Trim Page

	Date Page Created	07 Jan 08 09:50 AM	Imports	Knit
None	Date Page Modified	07 Jan 08 09:51 AM		
Summer 2008	Page Modified By		Content:	100% Cotton
5 Girls	Block #:		Fabric:	RUWI
97 Graphics	gg/Sz/E/wt:		Fabric Desc:	Soft Sueded Jersey

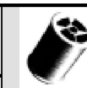
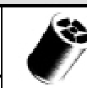
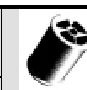
Item Information	Qty	Location / Color - Selling:	01 OPTIC WHITE	02 IRIS PINK	03 LUKA PINK	04 KEELSTONE NAVY	05 JOPLIN GREEN	06 BO4b HEATHER GREY	Representative Image
			Vendor Ref #	Vendor Ref #	Vendor Ref #	Vendor Ref #	Vendor Ref #	Vendor Ref #	
1 Wet Processing: KNITS WASH Finish Wash Standard Content: Weight: Width/Size:	0	GARMENT	Super Soft Soda Ash Wash KNITS WASH	Super Soft Soda Ash Wash KNITS WASH	Super Soft Soda Ash Wash KNITS WASH	Super Soft Soda Ash Wash KNITS WASH	Super Soft Soda Ash Wash KNITS WASH	Super Soft Soda Ash Wash KNITS WASH	Image Not Available
COMMENTS:									
2 Fabric - Knits: Soft Sueded Jersey Content: 100% Cotton Weight: 150 gms/m²AW Yarn Sz: 30/1	0	BODY AND SLEEVES	Optic White	Iris Pink	Luka Pink	Keelstone Navy	joplin green	Bros B04B	
COMMENTS:									
3 Fabric - Knits: Soft Sueded Jersey Content: 100% Cotton Weight: 150 gms/m²AW Yarn Sz: 30/1	0	INTERIOR BACK NECK TAPE	Optic White	Iris Pink	Luka Pink	Keelstone Navy	joplin green	Bros B04B	
COMMENTS: 3/8"									
4 Rib Trim: RIB Rib Trim (see comments) Content: Weight: Width/Size:	0	NECKBAND	Vendor Sourced/ DTM/ 1X1 RIB	Vendor Sourced/ DTM/ 1X1 RIB	Vendor Sourced/ DTM/ 1X1 RIB	Vendor Sourced/ DTM/ 1X1 RIB	Vendor Sourced/ DTM/ 1X1 RIB	Vendor Sourced/ DTM/ 1X1 RIB	Image Not Available
COMMENTS: RND TRIM 161/162/167									
5 Thread: Coats Epic Tex24 Content: Poly wrapped Poly Weight: Width/Size:	0	ALL SEAMS	Coats/ DTM DTM	Coats/ DTM DTM	Coats/ DTM DTM	Coats/ DTM DTM	Coats/ DTM DTM	Coats/ DTM DTM	
COMMENTS: BALL POINT NEEDLE									
6 Thread: Coats Epic Tex30 Content: Poly wrapped Poly Weight: Width/Size:	0	ALL EXTERIOR STITCHING	Coats/ C9199 White Russian* C9199 White Russian*	Coats/ C3101 Jupiter Pink C3101 Jupiter Pink	Coats/ C3715 Festive Red* C3715 Festive Red*	Coats/ C7915 Midnight* C7915 Midnight*	Coats/ C5349 Asia Sage #2 C5349 Asia Sage #2	Coats/ C9404 Jurassic Steel C9404 Jurassic Steel	
COMMENTS: BALL POINT NEEDLE									
7 Thread: COATSEPICTEX30 Coats Epic Tex30 Content: Poly wrapped Poly Weight: Width/Size:	0	ALL EXTERIOR CHAINSTITCH	Coats/ C9199 White Russian* C9199 White Russian*	Coats/ C3101 Jupiter Pink C3101 Jupiter Pink	Coats/ C3715 Festive Red* C3715 Festive Red*	Coats/ C7915 Midnight* C7915 Midnight*	Coats/ C5349 Asia Sage #2 C5349 Asia Sage #2	Coats/ C9404 Jurassic Steel C9404 Jurassic Steel	
COMMENTS: BALL POINT NEEDLE									

Figure 14. Fabric and sewing thread specifications. Source: Company RR2

SOLICITUD CALIDAD

Fabric Specification Sheet

Customer	Board/Style/Prog.
Customer Ref.#	
Season	Contact
Structure	Date Requested
Fabric Description	Date due

Development Number

Dye Method

CODE TIM	
Key 1	
Key 2	
Key 3	

Feed/Auto/Placement

Fabric content

TECHNICAL DATA [MACHINE]	
	Data
Machine diameter	
Machine gauge	
WPI	
CPI	
Course lenght [in]	
Unravel [100 Ndls]	
Number of needles	
Stitch lenght [in]	
Mullen Burst (ASTM 3786) [PSI]	
Twisting (AATCC 179) [%}	
Twisting (AATCC) [in]	
Max.Feed Stripe Repeat [in +/-1/8"]	

Dimensional Change

Fabric Description

Customer Ref.#

TECHNICAL DATA [YARN]				
Yarn count	Count system	Type yarn	Ends/Feed	Yarn content

TECHNICAL DATA [FABRIC]	
	Data
Greige weight [g/m2]	
Finished weight [g/m2] (AATCC)	
Washed weight [g/m2]	
Open width cuttable [in]	
Open width total [in]	
Washed tubular width [in]	
Finished tubular width [in]	
Shrinkage wash [% Lenght]	
Shrinkage wash [% width]	
Shrinkage AATCC 135 [% Length]	
Shrinkage AATCC 135 [% width]	
Wash cycle	
Finish	
Yarn Twist Constant.	

Special instructions

Order number [ODP]

Roll Number

Machine Number

Color

Date

Comments

UNIVERSALTEX R&D

Figure 15. . Fabric specifications sheet. Source: Company CS1.

On the other hand, retailers that contact vendors directly commented that it gives them more control over the production stages; they save money by avoiding the agent's fees, and it allows them to better control and negotiate prices; it also requires a developed quality assurance program on the retailer's side

As seen in Figures 14 and 15, at the retailer's level, the product specifications focus on the fabric characteristics rather than the yarn characteristics. Retailers RR1, RR3, RR6 and RR8 explained that if they request other specific yarn characteristics, it would be when they are re-sourcing the fabric with alternate sources to duplicate the quality of the existing source. They normally do not get into highly detailed specifications as hairiness, twist multiples, staple length, tensile strength as they rely on the fabric development testing and garment testing to gauge the results of the performance of the fabric. If the fabric passes all of the standard fabric testing such as pilling after laundering, random tumble pilling, appearance retention after launderings, etc.; they know that the overall quality of the yarn that was used was sufficient or exceeded their requirements for quality standards for their consumers. They will get in contact with the mills only if there is a quality problem that needs to be investigated.

Retailer RR4 commented that for products aiming niche markets, made of special and expensive materials they will specified in much more detail, but for cotton and poly-cotton, considered commodity items, they have several suppliers for the same product, quality is assumed and other are the factors influencing the supplier selection.

The majority of the retailers commented that when they tried to specified commodity yarns in more detail, they have received complaints from their vendors indicating that that was decreasing their flexibility, forcing them to buy yarn from a source that was not as efficient as their already established suppliers.

Vendors are the owners of the final product; they are in charge of looking for fabric suppliers based in the specifications received form the retailers or agents. The three vendors interviewed are vertically integrated. Two of them manufacture from the yarn to the final product, the third one buys yarn from U.S. manufacturers to make their own fabric, cut and sew it.

Having all the manufacturing processes integrated allows these companies to develop the fabrics based on the specifications received from their customers, and also considering the requirements of the manufacturing processes. Their product development teams coordinate with the manufacturing areas things like the type of fabric dye required for special printing techniques, or to obtain specific distressed looks; the type of feel hand the customer wants, etc.

The responsibility of translating these requirements into fabric and yarn characteristics relays on the fabric and yarn manufacturing areas. When the fabric requires to be made of specialty yarns like very fine or coarse counts, special blends, slub patterned, heathers, or made of special fibers; they source the yarn externally, in some cases from U.S. yarn manufacturers.

When the vendor is not vertically integrated they will pass the fabric specification sheet directly to the fabric manufacturers they work with. Four fabric and one sewing thread domestic manufacturers were interviewed at this stage. The denim and the sewing thread manufacturers make products for most of the retailers previously interviewed, two of them make fabric for bedding and bottoms and the last one is a knitting contractor; covering all the products selected for the research.

Four of the companies interviewed at this stage make their own yarn, and they also buy yarn from domestic yarn manufacturers when either they can not cover their own demand or when they do not have the equipment to manufacture it themselves. Once again, fabric and yarn manufacturers are responsible of specifying the yarn characteristics relays on the fabric and yarn manufacturers.

It was observed during the visits to the plants of some of the companies and the R&D departments of some retailers (FM1, CS1, RR1 and RR3) that most of the time fabrics are submitted in garment for approval, allowing the designers to evaluate the look, hand and distress effects in the final product. Simultaneously a fabric hanger and a spec sheet are sent.

The yarn specifications provided for the products selected for this research are basically the same: count, type and content for the fabric yarns and specific codes indicating the supplier for the sewing thread as shown previously in Figure 13. Detailed yarn characteristics such as Uster % CV, hairiness, tensile and elongation properties remain recorded in the libraries and data management systems of the yarn manufacturers.

Special notes must be made for denim fabrics and sewing thread. In both cases the retailers nominate the supplier in the technical package. The fabric manufacturer FM1, indicated that actual fashion trends required engineered design of denim fabrics, specific slub patterns (width, length and frequency) on filling and warp yarns give a specific character to a fabric; usually customized for every brand or retailer, therefore specific fabric codes are specified in the technical packages.

The importance of the look of the fabric has brought together designers, fabric and yarn manufacturers into the development process, and the yarn characteristics specified in this case are pretty detailed.

The sewing thread manufacturer (FM5) has developed a program to work with the designers to help them understand the properties of the sewing threads and how to select the best one as a function of the final product. With so much production made in Asia, if the sewing thread type and the composition is not specified, vendors automatically order spun polyester, because is cheaper and shinier, but this is not the optimum yarn for all fabrics and sewing and embroidery machines. Therefore, besides the color, the specific type and manufacturer code needs to be specified.

Three of the yarn manufacturers that participated in the research (YM1, YM3 and YM4) produce specialty yarns, YM2 is considered a large cotton yarn manufacturer and YM5 is recognized for its synthetic yarns. The three specialty yarn manufacturers maintain a closer relationship with the retailers compared to the other two; they contact them directly and occasionally will participate in the development process.

Interviewees representing the five companies in the group of fabric manufacturers said that they are knowledgeable enough to specify detailed yarn characteristics. The interviews with the yarn manufacturers confirmed that there are still some other fabric manufacturers that need their technical advice defining the best suitable yarn characteristics for their products.

Based on experience, yarn manufacturers YM1 and YM5 will select the most appropriate yarn for a specific application and send a first sample shipment to their clients, then, a fine-tuning process will occur until the customer feels comfortable with the results. At this point the yarn specs will be set. Figure 16 shows the most complete specification sheet obtained from the interviews to the companies at this stage.

Machinery manufacturers (MM1 and MM3) think that yarn specifications are important to design the machines and define the operation settings. They work together with yarn manufacturers and fiber suppliers in the presentation of new fibers or cotton varieties and their application on final products.

Presently only a few fabric and yarn manufacturers can afford a Research and Development department. Yarn, machinery and fiber manufacturers use three of the research organizations interviewed to develop new products and to learn about machinery settings, product performance and specifications, and testing.

Date	1/24/08	Yarn Count	7.25 #078 4.38
Source	PKD#35	Tube Color	grape /yellow
Trailer	1283	YN#	YN0026
B.O.L.	39797	Sample Size	4
Tech.	CS	Week Number	

Revison Date: 10/01/06

Property	Stop Off	LSL	Off Standard	LWL		Standard		UWL	Off Standard	USL	Stop Off
Weight(skein)		7.01		7.16		**7.25**		7.44		7.59	
CV%		18.21		19.27		**20.33**		21.39		22.45	
Thick (35%)		225		442		**659**		876		1093	
Thick (50%)		11		44		**77**		110		143	
Thick (70%)				1		**2**		3		4	
Thin (40%)		223		252		**281**		310		339	
Thin (50%)						**13**		32		51	
Nep (140%)		14		17		**20**		23		26	
Nep (200%)						**1.00**		1.55		2.10	
Breakforce		1193		1259		**1324**		1389		1454	
Breakfactor		2184		2272		**2359**		2446		2534	
Tenacity		15.37		16.05		**16.73**		17.41		18.09	
Elongation		7.44		7.77		**8.09**		8.41		8.74	
Cyros Data											
OCV%		13.34		14.34		**15.34**		16.34		17.34	
Thicks (Cyros)		383		459		**535**		611		687	
Thin (Cyros)				31		**65**		99		133	
+40%@25-50mm		41		59		**77**		95		113	
+30%@25-50mm		162		193		**224**		255		286	
HAIRINESS		7		8		**9**		10		11	

Figure 16. Yarn specifications. Source: Company FM1.

These three research organizations have fully equipped textile laboratories and companies use that service mainly to control the quality of the products they are receiving from their suppliers.

Research organizations act like a liaison between the textile manufacturing side of the supply chain and the retailers. RS1 for example helps textile manufacturers to find the best final application for their new developments and how to present it to their customers. For some socks manufacturers working with the organization RS4 has been the only way to reach retailers and a good way to have access to latest technology and training. The interviewee at RS4, indicated that retailers highly appreciate the impartiality of these organizations, that is why they will come to them when looking for new suppliers or evaluating actual ones. From the point of view of the retailers interviewed, they based their quality standards on those developed by the organization RS2 and apply some business and manufacturing models developed by RS3.

4.2. Yarn Specifications and Standard Testing Methods

All case study participants were asked to indicate what where the yarn characteristics frequently specified in the industry when either sourcing or selling yarns. Figure 17 shows the number of responses obtained for each yarn characteristic. Absolutely all the companies interviewed (n=32) indicated yarn count, fiber content and yarn type (ring spun, open end, air jet, combed or carded). At the retailer side as well as at one of the research organization these were the only three mentioned.

After identifying the yarn characteristics most frequently specified, the testing methods and equipment used to measure them were investigated. At the retail level, the majority of their testing and verification is done in garment or finished fabric. All six retailers request their suppliers to send the samples from product development and production to designated independent laboratories.

The laboratories test the fabrics under the specifications requested by the retailers and sent a testing report to the retailer and the supplier. Five of them use AATCC standards testing methods and one of them is switching to ISO because is more convenient for their suppliers offshore. All six use the service of one of the laboratories mentioned.

Two retailers shared examples of suppliers that have been working with them for years, and in order to speed up the testing process, the retailer has certified the supplier's testing laboratory.

The interview with the research organization RS4, revealed that in the hosiery industry, AATCC, ASTM and ISO standards are used, but in many cases only as references.

Traditional testing methods needed to be modified due to the size of the hosiery products, the number of fiber types, blends and the different fabric structures used to make a sock. A hosiery consortium of hosiery manufacturers, suppliers, retailers, testing labs, North Carolina State University College of Textiles, the North Carolina Manufacturing Extension Partnership (NCMEP), the Carolina Hosiery Association (CHA), The Hosiery Association

(THA), The American Association of Textile Chemists and Colorists (AATCC) and The Hosiery Technology Center (HTC) worked to establish standard methods for testing fit, abrasion and colorfastness of hosiery products.

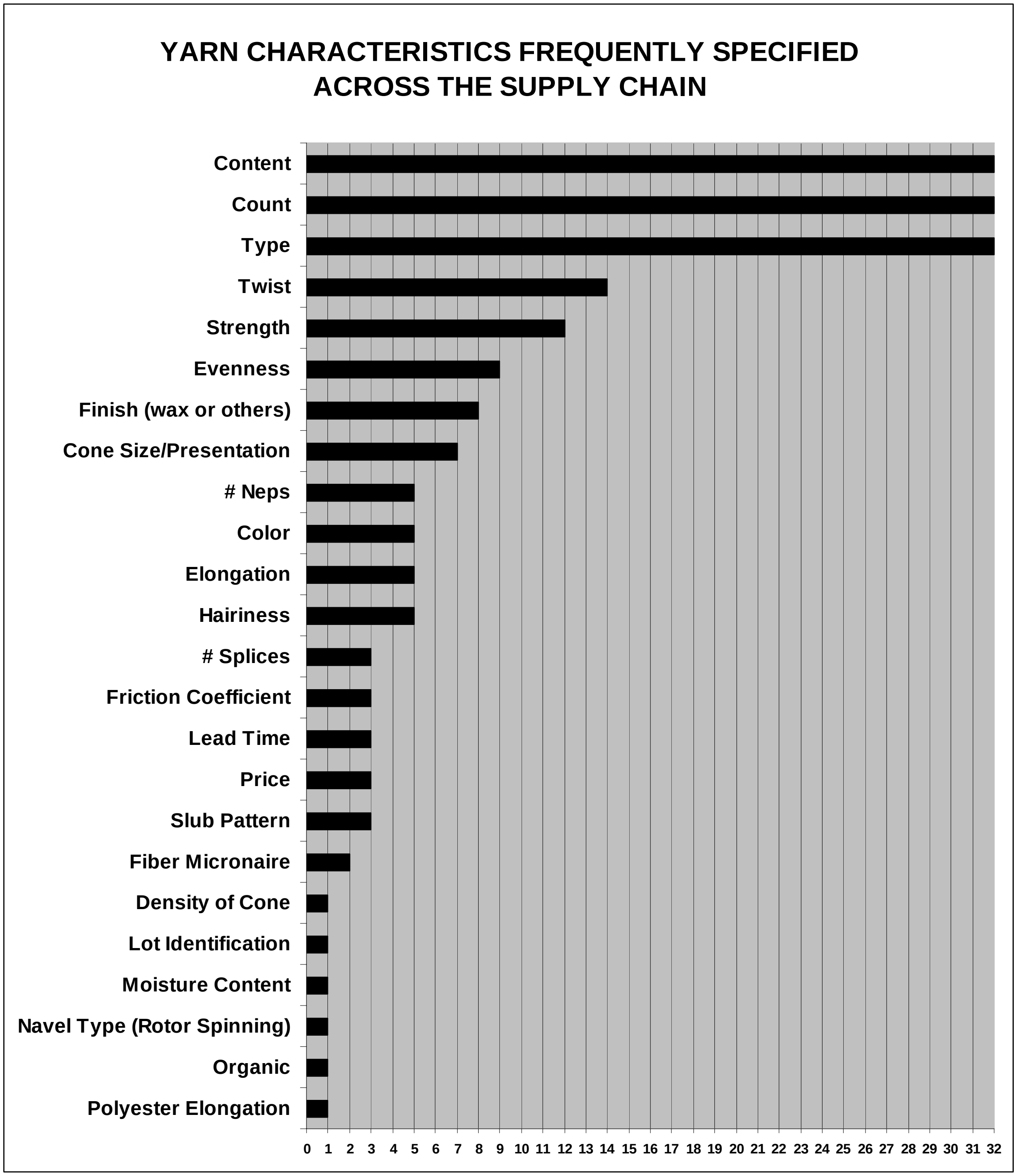


Figure 17.Yarn characteristics frequently specified across the supply chain. Sample size n=32.

An example of the page that includes yarn specifications in a typical fabric testing report sent to retailers is shown in Figure 18, it was provided by retailer RR2 and it was found that RR1, RR2, RR3 and RR6 receive similar reports. It can be observed the yarn count and fiber content are the only two characteristics tested for yarns.

Although retailers RR2 and RR8 have the capability of testing basic yarn characteristics at their facilities, and all the others can do it at external laboratories, they normally do not do yarn testing. Based on the interviews and visits to companies it was observed that yarn manufacturers do the majority of the yarn testing (not machinery of fabric manufacturers) because they have the equipment and it is usually updated. Buying this equipment is too expensive and not that necessary for the fabric manufacturers. They rely on information from the key mills that furnish all pertinent yarn specification information. Detailed yarn specifications like CV%, strength, evenness, etc, are requested only if there is a quality problem or because they want to reproduce the product in other factories and make the product to look the same in the shelves at the stores.

ITEM TESTED			TEST REQUESTED	
Development			Basic Fabric Package	X
Pre-Production	X		Basic Garment Package	
TOP/Bulk			Fabric & Garment Package	
Fabric	X		Trim or Accessory Package	
Trim			Individual Test	
Garment			**PREVIOUS TEST #**	
Test Submit is:	**Before Wash**		**List Specified Wet Process**	
	After Wash	X		
Marketing:	**Not included**		**List Marketing Type**	
	Included			
Water Resistance Claimed			**Actual**	

SPECIFICATIONS **Actual: Confirmed by MTL Test results**

Country of Origin:		
Fiber Content:	Claimed	100% Cotton
	Actual	100% Cotton
	Suggested	100% Cotton, Pending Garment Review
Construction:	Claimed	(Wales x Courses) Single Jersey
	Actual	(Wales x Courses) Yellow: 31x43, Olive & Navy: 31x41, Brown: 31x40 Single Jersey
Weight:	Claimed	(Gr. / M2) 200 AW
	Actual	(Gr. / M2) Yellow: 203.8, Navy: 204.8, Olive: 201.4, Brown: 204.8
Width:	Claimed	(Inches) N/L
	Actual	N/R
Yarn Size:	Claimed	(Cotton Count) 20/1 Ne
	Actual	(Cotton Count) 19.6/1

Figure 18. Example of yarn characteristics included in a fabric testing report sent to retailers. Source: RR2.

Product development teams at the retailer level recognize the influence of yarn specifications in the quality of their products. RR1, RR3 and RR6, commented that not everything depends on the yarn, there are other processes in between that will affect the quality and the esthetics of the fabrics. Finishes process can modify the looks, durability and other properties of the fabrics. In some cases yarn quality issues can be covered by an appropriate finish and in other an inadequate finish can decrease the strength and performance of the yarn and the fabric. At the end, retailers would care about the overall performance of the final products.

The vertically integrated vendors and fabric manufacturers interviewed, have fully equipped laboratories able to measure any type of yarn characteristic. The contractor knitter interviewed is the only one that outsources testing services.

The thirteen companies from the yarn, fabric and cut and sew links were asked to list the yarn characteristic they measure, the standard testing method and the equipment they use for testing. Seven of them responded and all confirmed to be using ASTM standards. Six of them failed to identify specific ASTM standard testing methods although they test the same yarn properties tested by the seventh company. They mentioned several Uster® indicators and measurement parameters considered as standards for them.

The summary of the answers are in Table 9. Although more than one machine was mentioned to measure the same yarn characteristic, it is noticeable that Uster ® equipment is used in the majority of the plants. Methods and equipment used to test yarns are relatively standard for both domestic and international companies.

Table 9.Yarn properties and equipment used for testing.

Yarn Characteristic	Equipment	N=7
Single end Tensile Strength & Elongation	Instron	1
Single end Tensile Strength & Elongation	Textechno Statimat-M	1
Single end Tensile Strength & Elongation	Uster Tensojet	4
Single end Tensile Strength & Elongation CV%	Uster Tensojet	3
Skein Break	Scott Tester	3
Yarn Twist	Mesdan Twistmatic	4
Friction (Yarn to Metal)	Lawson-Hemphill Friction Tester	2
Friction (Yarn to Metal)	Mesdan Friction Meter	1
Identification of Periodic Mass & Hairiness Defects	DS65 ILE tester	1
Identification of Periodic Mass & Hairiness Defects	Uster Tester 3	2
Identification of Periodic Mass & Hairiness Defects	Uster Tester 4	2
Yarn Appearance	Board	1
Yarn Evenness	DS65 ILE tester	1
Yarn Evenness	Uster Tester 3	2
Yarn Evenness	Uster Tester 4	2
Yarn Hairiness	Uster Tester 3	2
Yarn Hairiness	Uster Tester 4	2
Yarn Mass CV%	DS65 ILE tester	1
Yarn Mass CV%	Uster Tester 4	1
Yarn Count	Scale	3
Yarn Count	Uster Tester 3	2
Yarn Count CV%	Uster Tester 4	1

Since fabric and yarn manufacturers are in charge of generating the yarn specifications, the information at these stages is much more detailed, as seen in Figures 16 and 19, examples of the spec sheets of one yarn manufacturer and fabric manufacturer.

Quality Parameters on Cones

Date: 3/21/2008

Item: Supima ; Ne 30/1 ; Z
waxed ; hard
19.56 TPI (3.57 TM)

Count (Autosorter III)	Ne	30
	CV %	1.30
Strength (Tensojet) 5000 mm/min.	cN/tex	30.11
	CV %	6.57
Elongation	E %	5.60
	CV %	5.80
Evenness (UT 3)	CV	11.06
	Thin -50% / -40%	0 / 11.5
	Thick +50% / +35%	13.1 / 134
	Neps +200% / +140%	35.9 / 187
Hairiness (UT 3)	Hx	5.07

Figure 19. Example of yarn spec sheet. Source: YM1

Additionally, companies were asked to identify what where the most important yarn specifications they would consider for specific applications. The following tables summarize the answers of yarn and fabric manufacturers regarding denim and t-shirts.

Table 10.Important yarn specifications for denim.

Yarn Specification	FM=1	YM = 5
Strength	1	3
Count	1	2
Runability	1	2
Slub Pattern	1	2
Consistency	1	1
OCV%	1	1
Mentioned by FM, omitted by YMs:		
Cost	1	0
Delivery	1	0
Size	1	0
Twist	1	0
Important from the point of view of YMs, no relevant for FMs:		
Hairiness	0	1
Evenness	0	3

Table 11.Important yarn specifications for t-shirts.

Yarn Property	FM = 4	YM = 5
Count	3	2
Finish (wax, PFD)	3	1
Twist	3	1
Evenness	1	2
Strength	1	2
Fiber Content	1	1
Mentioned by FMs, omitted by YMs:		
Cost	2	0
Delivery Time	2	0
Yarn Type	2	0
Mass CV%	1	0
Important from the point of view of YMs, no relevant for FMs:		
# Neps	0	1
Coefficient friction	0	1
Dyeability	0	1
Elongation	0	1

Tables 10 and 11 show how yarn and fabric manufacturers differ in their appreciation of yarn characteristics, there is also difference among the yarn manufacturers, that is why some characteristics were mentioned only by one of the five yarn manufacturers interviewed.

In Table 10 for example, only three of the five yarn manufacturers agreed that strength was important and then the other characteristics where mentioned by two or even only one yarn manufacturer. There are also yarn characteristics that the denim manufacturer considers important but were not mentioned by any of the yarn manufactures. Finally, three of the five manufacturers indicated that evenness is very important, but is not for the denim manufacturer. In the case of t-shirts something similar happens. Not enough answers for socks, sheets and sewing thread were obtained to allow a comparison.

From additional comments made by **fabric manufacturers** (FM2, FM3, FM4, and CS1) during the interviews it was observed that yarn used in commodity products is easy to obtain, they just call a supplier, request yarn indicating the count, the content and the type. Yarn needs to be of a quality that allows machines to run at good efficiency levels, and have a good price.

Runability is the result of several yarn characteristics; it is difficult to define which one is the most important without making trials in production. Yarns do not need to be perfect, a smoother yarn is good but evenness is not the only characteristic that will contribute to the runability.

Three of the five yarn manufactures (YM1, YM2, and YM5) as well as fabric manufacturers FM2 and the vendor CS1 were concerned about the consistency of the product. The break strength and consistency between lot and lot are critical factors. CV% values, IPI, hairiness and other detailed yarn characteristics, are usually tested at the fabric manufacturing stage when there are quality problems or when the supplier is new. These three yarn manufacturers are required to send the yarn certifying the quality and the change of lots if necessary, but the main testing points for yarns are the looms and knitting machines.

From the interviews with the **yarn manufacturers**, it was observed that detailed yarn specifications are used for internal controls only. Their testing data is recorded and the systems used to manage it allow yarn manufacturers to track a problem and identify specifically the part of the processes where it was originated. Variations in the yarn characteristics may not cause a quality problem to the customer but can cause operational problems at the mill. These data is use for optimization of opening, carding, drawing and spinning machines.

One of the yarn manufacturers (YM1) indicated that one of their customers, a large retailer, will specify in detail the yarn characteristics, will test and monitor every single property and offer a quick feedback; maybe not knowing exactly how those characteristics affect the fabric but using the data to control the consistency of the supplier.

In the case of poly-cotton blends, they are usually a bit more detailed because they include luster level and tenacity.

A executive interviewed at the organizations RS1, commented that fabric and yarn manufacturers understand that the important yarn characteristics to specify are those that will influence the look and hand feel of the fabric; they also know that the evaluation of these characteristics can be very subjective, and specifications are necessary to remove the subjective aspect when evaluating a yarns.

Based on the answers given by retailers RR1, RR2, RR3 and RR4, a **retailer** will give yarn specifications only if they want to assure the consistency of their products. These specifications were generated at the mill that got approved as a fabric supplier, and that after negotiations decided to supply a complete program, in that case they need to provide yarn specifications that the retailer will use as their standard and run periodical tests (usually twice a year) to check the consistency of the product. This is common for core fabrics (those that are part of the collection, season after season), for fashion items, they will not do it.

4.3. Order Wining Criteria and Performance Metrics

Once it was determine what links of the supply chain are in charge of generating the specifications and which specifications are the most important to be considered, it was necessary to study how can we use this information to help yarn manufacturers to remain competitive and differentiate their products from offshore sources.

All thirty two companies were asked to indicate what were the criteria used to select suppliers. Seventeen companies answered, revealing that quality was the most important factor, followed by price and delivery (Figure 20).

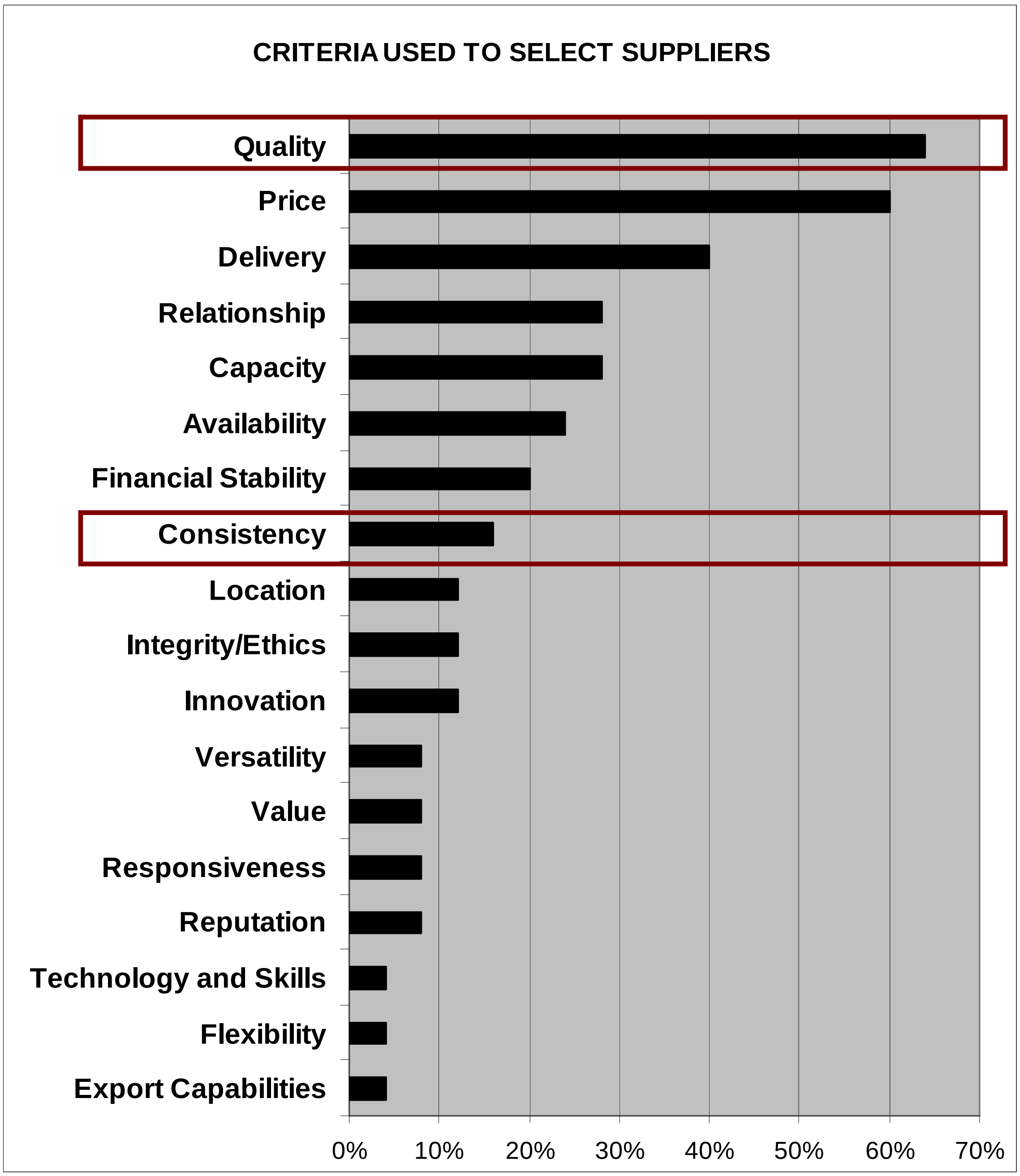


Figure 20. Criteria used to select suppliers across the supply chain. (n=17).

Note that quality and consistence are the only two aspects related to product characteristics; the others involve logistics and business related practices.

From the visits and interviews it was observed that **Quality** is assumed if you are in business today. Without the right quality, price is of no consequence. Successful companies have been able to achieve their own standards, the ones required as a function of the end use of the product, at the lowest cost possible. Quality is not always evaluated based on a specification sheet or a testing report, instead, the accumulation of positive results from previous experiences with the supplier. Retailer RR1 believes that degree of development of the quality program or the quality controls at a yarn mill reflects the quality of the product and this is something that they consider very important when selecting suppliers. If retailer RR2 decides to run a core fabric in big volumes, they request the vendor to tell them who is the yarn supplier and then they will go to evaluate their facilities and their quality program.

Regarding **price**, it is not just about the yarn price, it is about the yarn price and the finished fabric price. For retailers, to simply look at the yarn price, over simplifies the study. They really have to look at the entire supply chain of a specific garment program before they commit to yarn/fabric for any order. A yarn supplier might be the lowest priced, but if the price of the finished fabric is too high due to mill inefficiency or cross regional duties then the spinner loses the order. Most of the interviewees commented that they will look for low prices without compromising the quality; that prices need to be competitive but not the cheapest.

Retailers RR2 and RR6 commented that **Delivery** issues are more serious than performance issues when deciding when to stop working with a supplier. Lead times and the capability of meeting quoted delivery dates and volumes are highly appreciated and monitored.

When there is a collaborative **relationship** between supplier and buyer, problems like late delivery can be forgiven according to retailer RR6. Vendors and retailers appreciate companies that can offer technical advise not only about their expertise in a specific process, but that understand and help them understand who yarn characteristics can help to prevent problems in subsequent process.

Five of the six retailers interviewed mentioned that a vendor needs to assure the retailer that the volumes they can produce are enough to cover a complete program. This is critical for the commodity core products discussed in this research; this is why **capacity** is important when selecting suppliers. Large companies can offer economies of scale and usually keep their machinery and technology updated. Retailer RR6 mentioned several examples of dropping off suppliers because they were overbooked or did not have the technical skills to make a good product. Capacity is related to the **financial stability** of the supplier, customers keep in mind if the supplier is able to obtain credit to buy raw materials and delivery order on time.

Availability is the key to generate continued sales according to yarn manufacturer YM2 and vendor CS3; the more places people can buy your products, the more sales you'll make. Availability is limited in the U.S. because they are only a few companies left making the products selected for this research.

Yarn manufacturer YM2 sustains that making commodity yarns is not a secret; anybody can do it in any place in the world. **Consistency** in the quality of the product as well as on the delivery times and prices is what differentiate yarn suppliers.

Finally, only one yarn manufacturer (YM2) and absolutely all the retailers commented that they consider **location** as an advantage. A yarn manufacturer would ideally have to be close or within the same region as the fabric manufacturer. Likewise, one would want the fabric mill ideally in the same region as the cut/sew partner.

Since this research focuses in domestic yarn manufacturers, the criteria to select suppliers across the supply chain (n=32) was compared to the criteria that fabric manufacturers used to select yarn suppliers (n=5) (Figure 21). It is observed that fabric manufacturers appreciate the following criteria more than the overall supply: Quality, Delivery, Relationship, Availability, Consistency, Reputation and Flexibility.

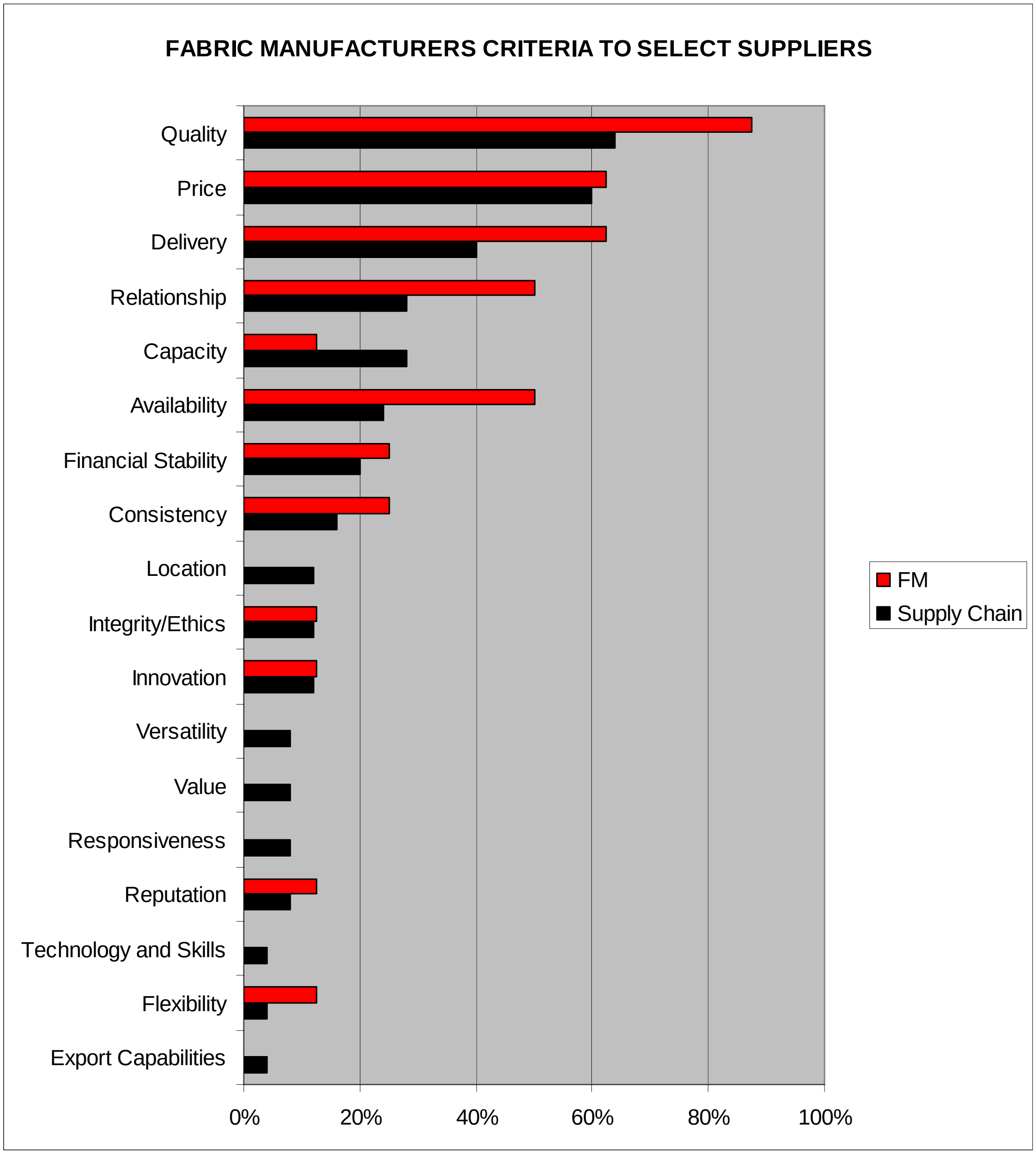


Figure 21. Fabric manufacturers' criteria to select suppliers.

To be able to determine if yarn manufacturers are aiming their efforts in the right direction they were asked to indicate why they think they have been chosen as suppliers.

The answers were compared to the fabric manufacturers' answers regarding the criteria they use to select suppliers. Note the difference on the areas of focus between yarn and fabric manufacturers. (Figure 22) Remember that this is a comparison between the answers of the five yarn manufacturers interviewed and the five fabric manufacturers. It can be observed that technical support and reputation are considered as a business strength by yarn manufacturers, but they are not appreciated in the same way by fabric manufacturers.

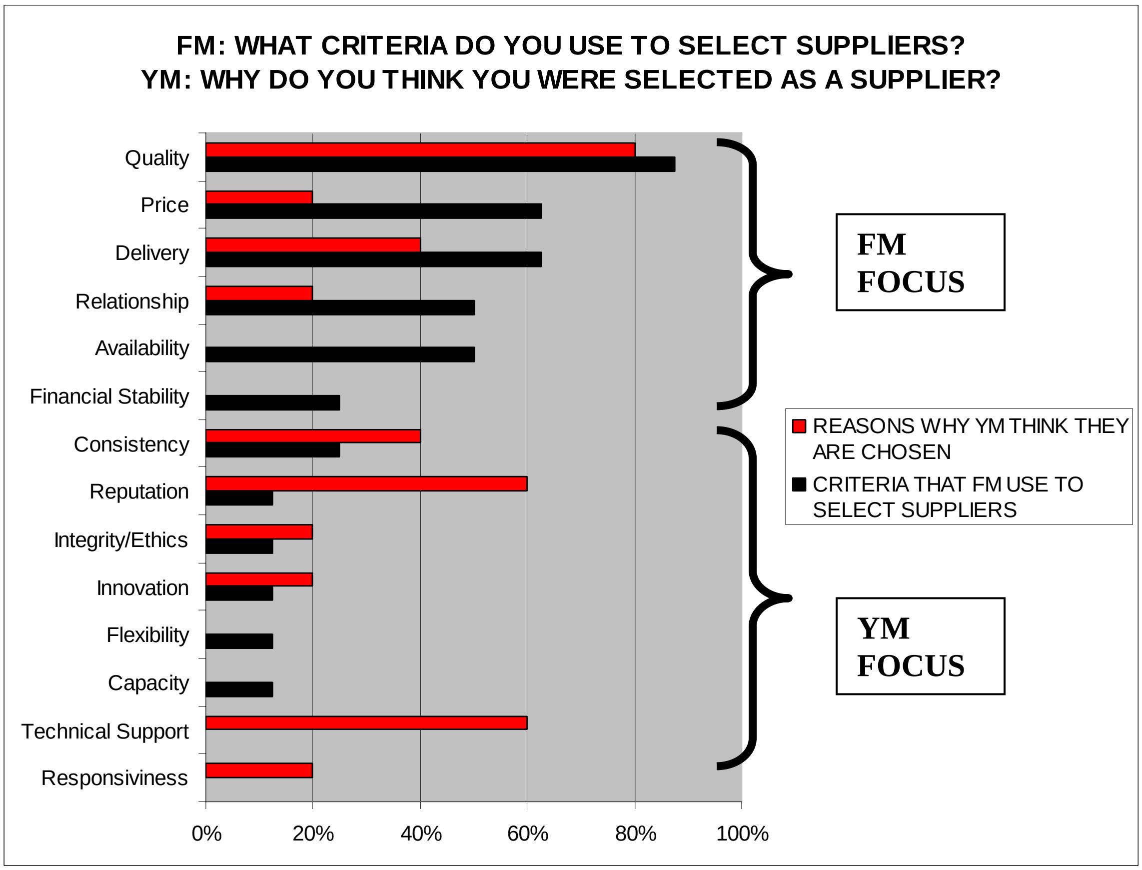


Figure 22. Supplier selection criteria across the supply chain.

Once the criteria to select suppliers were defined, the next question to be answered was how are they evaluating their suppliers? What indicators do they use? Are there any performance metrics systems being used?

Literature findings indicated suggestions made to manufacturing companies about putting more much emphasis on non-financial measures in comparison to financial measures in their performance measurement system, have not been followed. That net profit, gross profit margin, total sales department, amount of raw material inventory, cost per unit produce and others represented the first eleven measures mentioned by the companies. (Gosselin, 2005).

According to the findings of this research this is not the case when it comes to evaluate suppliers. For this evaluation, time related indicators are the most used. Ten of the thirty-two companies contacted answered this question. Four of the six responses to "meeting quoted delivery dates" were given by fabric manufacturers and a vertically integrated vendor. Only one retailer and one yarn manufacturer mentioned to use this performance indicator.

Based on the answers obtained, it was noticed that companies are missing structured performance metrics systems. Different responses were obtained from people working in the same company but at different areas.

Table 12.Suppliers performance indicators.

SUPPLIERS PERFORMANCE INDICATORS	
FINANCIAL	
Annual renew pricing	1
Credit worthiness	1
Price Variations	2
TIME RELATED	
Lead Time	4
Meeting quoted delivery date	6
Sample turnaround time	1
PRODUCT RELATED	
Conformance to specs	3
Processability	2
Product performance	2
Quality claims	3
Size of cones	1
Soil grassy	1
LOGISTICS	
Backorders	1
Damage in transport	1
Errors in paperwork	1
Short shipments	3
Truck turaround time	1

4.4. Product Data Management

The objective of this section was to identify the software and tools available in the industry to manage product data and to see how they incorporate yarn characteristics into the design of the final product.

From the interviews it could be observed that only basic yarn characteristics are considered into the design and product development at the retailer's side, as shown in the example of the technical package specification sheet in Figure 14, the driving factors are fabric swatches, hand, weight, content, and drape of fabric.

Product development and sourcing teams can build a product using known characteristics of specific yarn counts or types, but normally at the design level designers refer to finished fabric specs and physical fabric standards for decision making.

As explained in section 4.1. of this chapter, retailers use PDM (Product Data Management) and PLM (Product Lifecycle Management) software to support the product development process but they have the disadvantage of focusing on garments. They failed to incorporate the details of the textile components: fabric, yarn and fiber.

All the retailers interviewed, as well as the vendors and only one fabric manufacturer confirmed to have digital libraries that can be linked to PDM or PLM packages, where they record the fabric characteristics, knit-down designs, testing results, fabric approvals, etc. So when the time to look for a new fabric development comes, before starting from scratch they search these databases looking for similar fabrics.

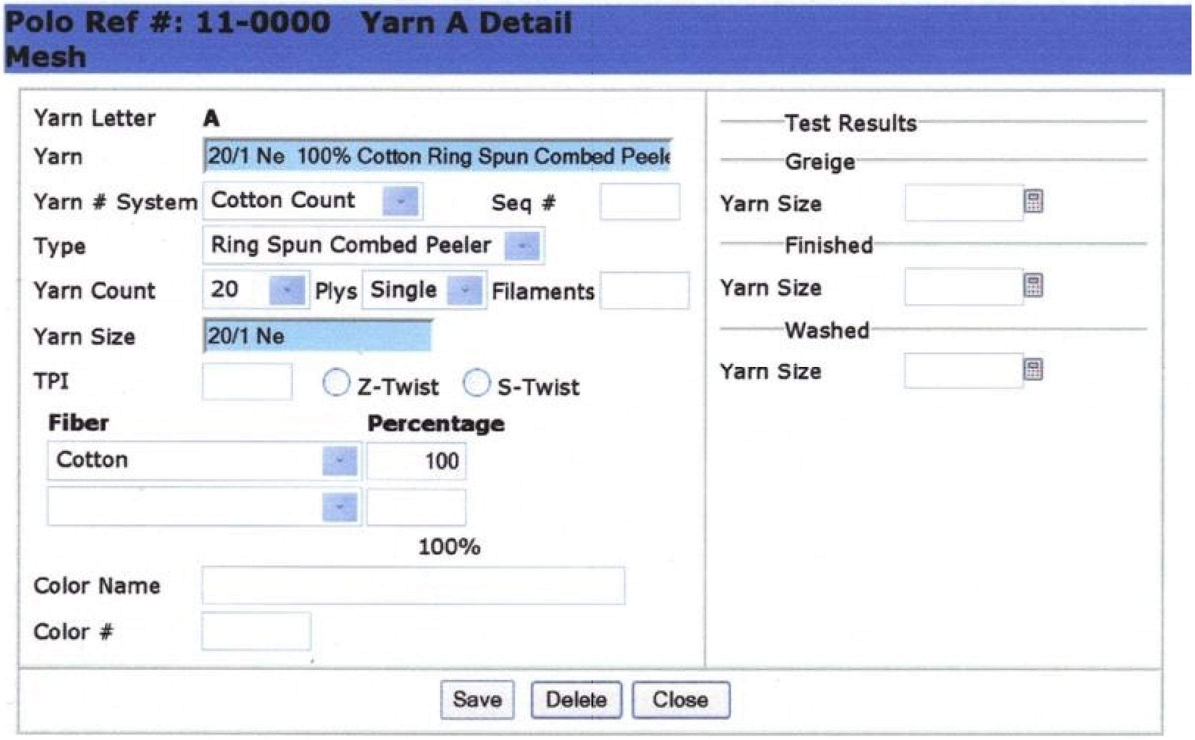


Figure 23. Yarn data store in fabric libraries. Source: RR1.

Large retailers like RR1, give access to their key vendors and mills to these systems, so they can fill the fabric and yarn specs directly from the factories, or use the library as a guide to develop or reproduce fabrics. The main benefit is that they can communicate with suppliers across the world and contribute to the uniformity and consistency of their products. But this is just a data base resource, is not a software program that will allow you to determine what could be the best yarn characteristics to achieve expected quality and fabric characteristics.

At the yarn manufacturer level, it was observed that product data is recorded whether in laboratory software or some sort of data base. Data is used to track a problem and identify specifically the part of the processes where it was originated.

Variations in the yarn characteristics may not cause a quality problem to the customer but can cause operational problems at the mill. These data is used for optimization of opening, carding, drawing and spinning machines, not to be incorporated in the design of the final product.

Two software programs that incorporate yarn characteristics into the design of fabrics were found during the research but can not be classified as PDM.

The first one is called Starfish. Developed by Cotton Technology International (1998). It is a computer program simulator that models the key elements of production and processing cotton circular knitted fabrics and it calculates their expected performance. The predictions provided by the program are usually within one standard deviation of the average measured values obtained from comparable fabrics in routine production. The parameters that can be chosen as input are fabric types, yarn types and settings for wet processing. The outputs are knitting specifications and finish fabric properties projections the following figures show screen shots of the yarn parameters that can be changed for the simulation.

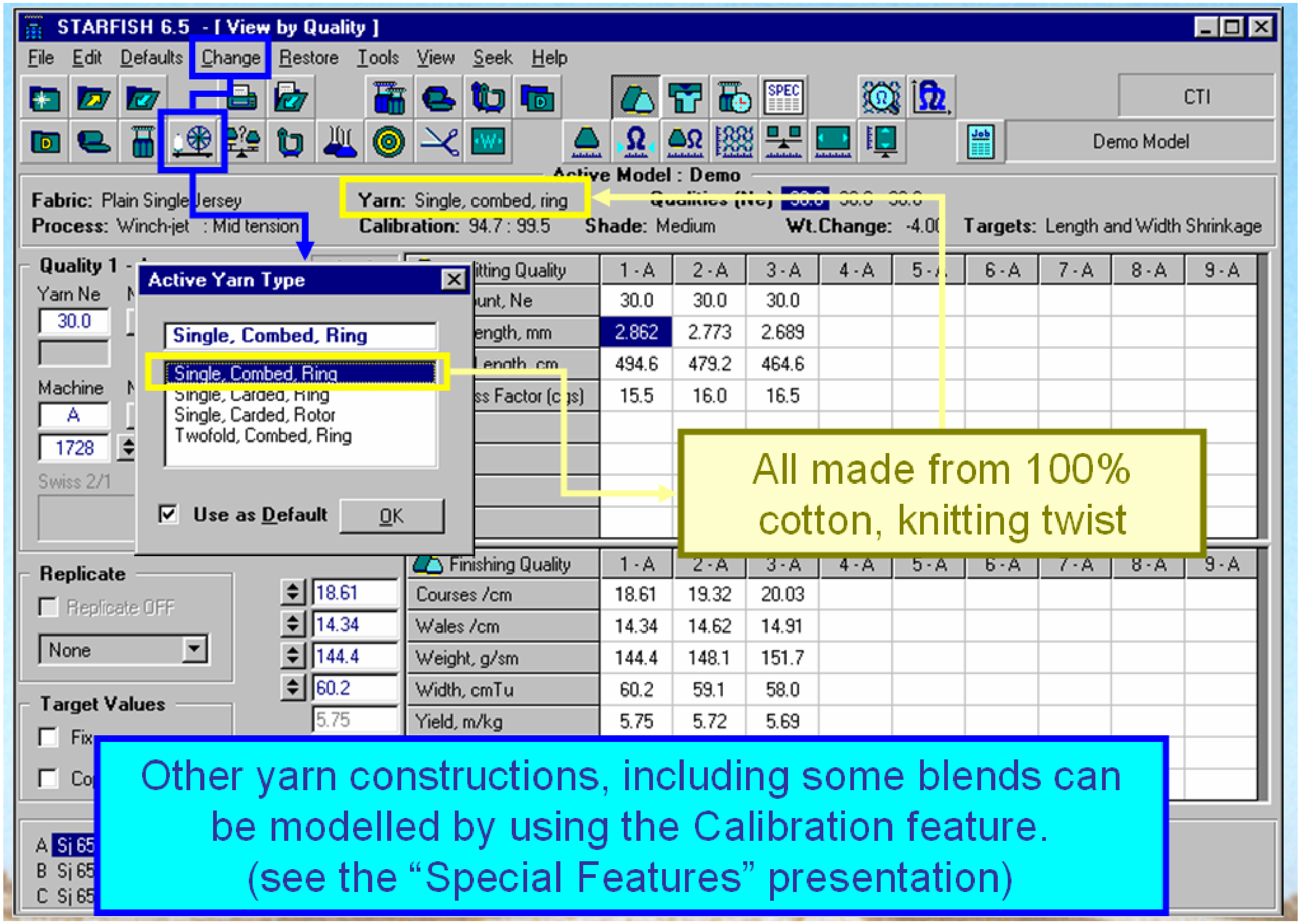


Figure 24. Starfish: Choosing yarn type. Source: Cotton Technology International.

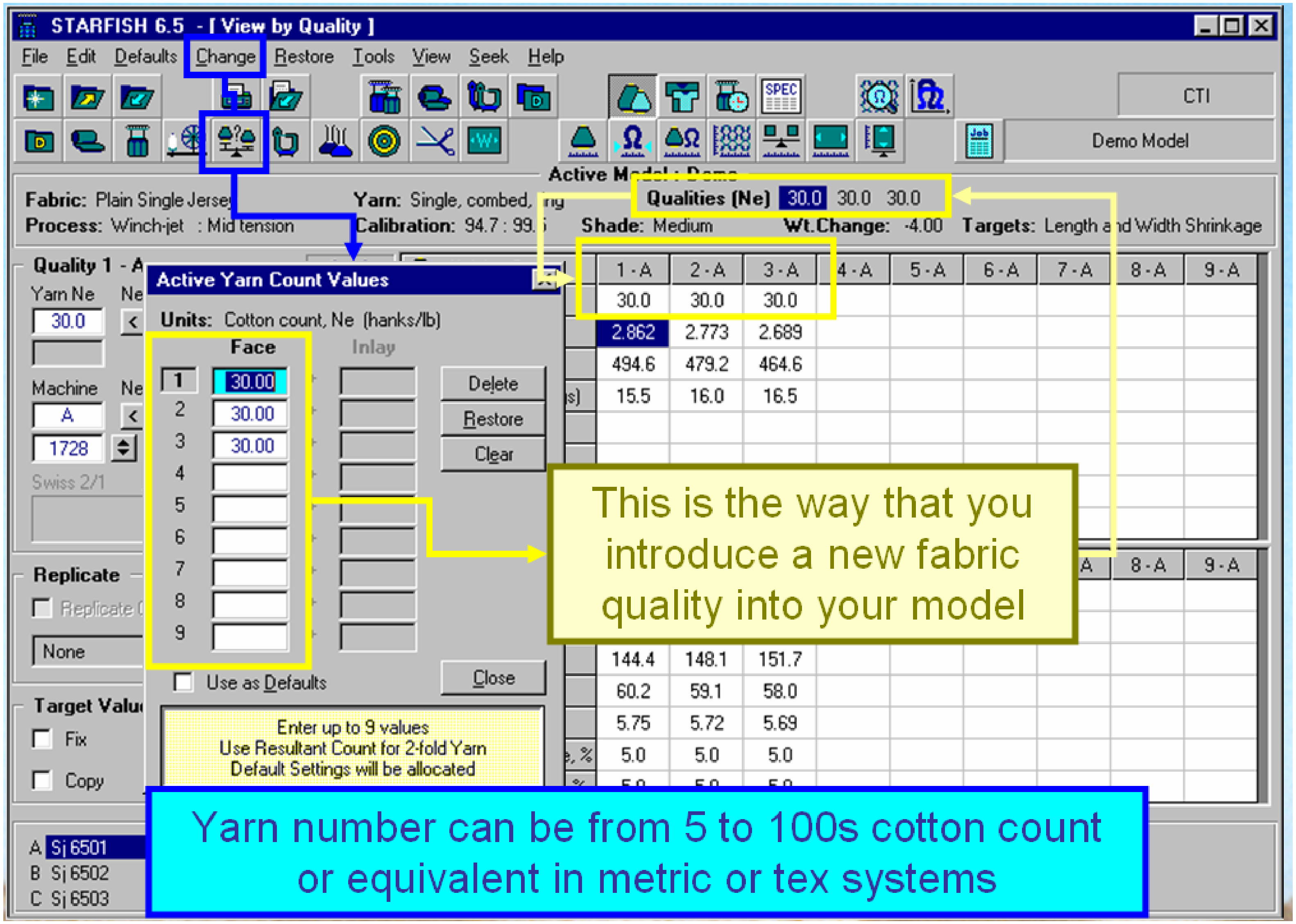


Figure 25.. Starfish: Choosing yarn count. Source: Cotton Technology International.

The other program founded is called CYROS®, a yarn-to-fabric computer simulation system that allows an existing yam to be "scanned" and the digitized information is fed into a software program that generates a technically correct fabric structure, knit or woven. Different yarn qualities and/or manufacturing parameters can be evaluated in a fabric construction without the expense of making the fabric. CYROS® was originally conceived to be a quality control tool early on, but its role has expanded to manufacturing as well. (Cotton Inc., 1999)

CYROS® development was defined by the following considerations (CIS Technologies GmbH, 2001):

- Spun yarn shows irregularities. These thickness variations affect the strength performance and the visual appearance of the final fabric, produced with the yarn.
- The quality control of the yarn is therefore an essential task in both yarn production and fabric production
- There are testing devices that measure the yarn thickness by capacitive or optical sensors. But they only do statistical analysis of the data. The calculated OCV% - values as a mean for the variation are useful but very often not significant enough to predict the visual appearance of the fabric. Therefore, yarn board tapering or sample production of woven or knitted fabrics is very common. This is time consuming and expensive.

Figure 26. CYROS® visualizes different degrees of washing effect in denim fabric. Source: www.cis.de

4.5. Business Practices

This section describes several practices which appear to drive success for yarn manufacturers and bring them closer to retailers; they were identified through not only discussions with yarn manufacturers, but from feedback at the fabrication and retail levels.

4.5.1 Quality (Qualifying Criteria)

On of the vertically integrated companies interviewed in Central America (CS2), buys yarn from Pakistan and the U.S. Pakistani yarn is usually 7.5% cheaper than American despite the trade agreements. Seventy percent of their production is made with American yarn. They recognized its superior quality compared to the Pakistani yarn and that is why they use American yarn for tops, where you need better hand feel and clean look, and Pakistani yarn for bottoms.

On the other hand, a retailer of high end products (RR2) indicated that the yarn quality they see coming from their vendors in China and India is quite superior to the domestic yarns. They have tried without success, to duplicate that quality working together with the yarn suppliers here in the U.S. and the vendors in Central America that buy American yarn. They said that American yarn manufacturers have positioned themselves for commodity type products and that their quality won't let them compete in high end markets.

4.5.2 Relationship (Winning Criteria)

Yarn manufacturer YM1 and fabric manufacturer FM1, both leaders in their markets, have maintained their reputation and their sales working with the supply chain to be sure that the previous and subsequent processes are also the best possible so that the final product results of a premium quality. A executive at YM1 commented that it would not be worth it to put a lot of effort doing quality yarns or fabrics, if subsequent process, such as finishing or sewing, are going to decrease that quality. Both companies work with their clients trying to improve the general performance of the supply chain.

Based on the opinions of the interviewees at the research organization RS1, the agent RR5, the vendor CS1, specs were generated to produce fast, at an efficient cost and to assure consistency; but by sending a spec sheet to all the suppliers around world will not always guarantee retailers to get what they want.

The advantage that yarn and fabric manufacturers have when they have been working with a retailer for years, is that they got to know their way of thinking, what they want and what they like, they understand the retailer's requirements and quality standards. This knowledge and a strong relationship allows yarn and fabric manufacturers to modify their products but still their customers, or develop new products, innovate, with high probability of being approved.

Some machinery (MM5), yarn (YM1, YM3 and YM4) and fabric manufacturers (FM1) started contacting the retailers directly and developing collaborative relationships. The machinery manufacturer took advantage of their reputation in the market and created a certification program for yarn manufacturers using their equipment. The machinery manufacturer has developed informative programs for retailers to explain them how yarn affect the quality of the fabric, they show retailers who their equipment contribute to monitor and improve the quality of yarns and what are the companies using this equipment and which ones are certified by the company. It is a win-win procedure. The executive interviewed at RS1 and a Quality Control associate of retailer RR3, agreed that retailer's sourcing and design departments that have people knowledgeable about textiles are more likely to make quick and appropriate decisions.

The three yarn manufacturers and the fabric manufacturers work closely with designers to translate their concepts into real products, this approach allows them to be the preferred supplier and allow their name to appear in the technical packages sent around the world.

4.5.3 Capacity, Availability And Location (Winning Criteria)

Three of the five domestic yarn manufacturers interviewed produce specialty yarns (Supima® cotton or heathers). They differentiated themselves from the big volume producers and offshore sources by specializing in specific cotton yarns and by accepting small orders that the large companies did not want to take; they do not have a minimum volume order when a new client request yarns.

Two of them are aware of the shortening fashion cycles and consider that immediate availability is an important factor for success. They have modified their manufacturing processes to increase their flexibility and they design their yarns focusing on functionality, trying to make "multipurpose" yarns, any improvement or innovation to be applicable to final uses.

Based on the interviews, it seems that retailers have set sourcing strategies looking at the entire supply chain and each link within that chain to produce the right product at the right price at the right time. They set regional strategies; therefore, the presence of a yarn manufacturer in that region is very important. Two retailers (RR6 and RR8) recognized the success of one of the yarn manufacturers interviewed, the commented about it aggressiveness to be closer to their clients and be able to supply the volumes required in that region.

Retailer RR1, RR2 and RR6, work with yarn manufacturers in those regions to maintain a certain level of business and keep them meaningful and efficient. Reviews of duty, quotas, freight transit and times are also very important.

As an example, vendor CS1 received a $3.18/lb quote for U.S. yarn and $5.45/lb for Peruvian yarn, both of similar quality. The buyer, located in South America had to choose the Peruvian despite the price, due to the lead times offered by the U.S. supplier.

Retailer RR6 recognized the capability of U.S. yarn manufacturers to decrease their production costs, but they complaint about their attitude when it comes to provide something different to their product offer. Another problem is the time domestic manufacturers take to make samples, offshore sources offer a seven day lead time for sampling, which includes the shipping time. Domestic manufacturers offer twenty-day lead times or more.

5 CONCLUSIONS AND RECOMMENDATIONS

The conclusions of this research are presented under the same five sections in which the results and analysis were presented in chapter four.

5.1. Yarn Specification Process

Domestic yarn manufacturers must address the requirements of all the participants in the textile and apparel supply chain in order to remain competitive and to differentiate their products from offshore sources. The objective of this project was to better understand these requirements through discussions with members of the supply chain.

To accomplish the first research objective: RO1:Map the yarn specification process across the supply chain; case studies were conducted with the participation of machinery, yarn, fabric and apparel manufacturers, as well as research and retail organizations. Both domestic and Latin American companies were pursued, and a total of 32 company interviews were conducted. The products investigated were denim, t-shirts, socks, sheets and sewing thread. All made of cotton or poly-cotton blends.

By studying the interaction between the links of the supply chain, the steps taken and considerations made at each link when specifying yarns, it was possible to identify that for the commodity products investigated, all the participants of the supply chain rely on yarn and fabric manufacturers to create the right yarn specifications.

Retailers and vendors focus on fabric specifications and will specify yarns only when there is a limited number of suppliers, the yarn is quite expensive or rare, or to control the consistency of their suppliers of core fabrics.

5.2. Yarn Specifications and Standard Testing Methods

Guided by the following research objectives:

- RO2. Identify yarn specifications considered important to yarn manufacturers, yarn buyers and other participants of the supply chain.
- RO3. Identify current standard testing methods and equipment used to evaluate yarn properties.
- RO4. Identify the most important yarn specifications as a function of the final product.

It was found that yarn count, fiber content and yarn type (ring spun, open end, air jet, combed or carded) are the most yarn characteristics frequently specified across the supply chain. Detailed yarn characteristics such as Uster® %CV, tensile properties, and surface characteristics are of interest of the mills to accomplish fabric specifications and to increase process performance.

Methods and equipment used to test fabrics and yarns are relatively standard for both domestic and international companies, the reason is that a specific company has a large portion of the textile testing machinery market in the east hemisphere, so domestic and international manufacturers have this equipment. Another reason is that the international companies supply goods to American retailers; therefore, they have to operate under the standards given by these retailers, which in general, are used to use AATCC and ASTM standard testing methods.

There is a visible difference between what yarn and fabric manufacturers consider as important yarn characteristics for specific products. Results presented in Section 4.2.of chapter 4, showed that a denim manufacturer considers yarn strength an important yarn characteristics to be consider, but only three of the five yarn manufacturers interviewed indicated that yarn strength was important. In the case of t-shirts, fabric manufacturers indicated that cost and delivery were yarn properties to be considered, none of the yarn manufacturers mentioned those two characteristics.

5.3. Order Wining Criteria and Performance Metric

The research objectives to satisfy under this section were:

- RO5. Identify performance metrics used by yarn manufacturers, yarn buyers and other participants of the supply chain.
- RO6. Define “order qualifying and order winning criteria” for domestic yarn manufacturers that will allow them to remain competitive and differentiate their products from offshore sources.

Performance metrics currently used to evaluate suppliers emphasize time related issues, such as lead times, meeting quoted delivery dates and sampling time. Time related indicators are the most commonly used to evaluate suppliers. Fabric manufacturers and a vertically integrated vendors, measure the performance of their suppliers according to their records of meeting quoted delivery dates, only one retailer and one yarn manufacturer mentioned to use this performance indicator. Based on the answers obtained, it was noticed that companies are missing structured performance metrics systems. Different responses were obtained from people working in the same company but at different areas.

Quality, price and delivery were identified as qualifying criteria for yarn suppliers, without satisfying these three requirements, domestic yarn manufacturers can not compete in the market. The criteria that allow yarn manufacturers to win orders, remain competitive and differentiate their products are: good customer relationships, capacity, availability, financial stability, product consistency and geographical location.

Offshore vertically integrated vendors as well as domestic fabric manufacturers consider buying domestic yarn that they can not produce either because technological limitations or to avoid decreasing productivity, this will be the case for fine counts, heathers and special blends.

5.4. Product Data Management

RO7. Evaluate existing product data management systems as to how they incorporate yarn characteristics into designing the final product.

Analyses of different software used to manage product data revealed that detailed yarn characteristics are rarely incorporated into final product design. Yarn testing data is important for yarn and fabric manufacturers to set the machines and to monitor them instead.

5.5. Business Practices

Several practices were identified which appear to drive success for yarn manufacturers. These practices were identified through not only discussions with yarn manufacturers, but from feedback at the fabrication and retail level. Development of relationships with retailers and a mixed of capacity, availability and geographical location were found to be key drivers for success among niche and commodity yarn producers.

The contribution of these research to the existing body of knowledge was to consider opinions from all the components of the supply chain and to obtain an in depth knowledge of the dynamics of the yarn specifications process through a multiple case study analysis. The findings will help yarn manufacturers to focus their efforts in the yarn characteristics and business practices identified as important for the other components of the supply chain.

5.6. Recommendations

- Yarn manufacturers should take advantage of being in charge of what needs to be specified, it is in their hands to determine the best quality yarn to fit a specific quality of the final product.
- There is available software to manage “product data" but detailed yarn specifications are not included because the data structure is simple. Trying to develop product data management systems for yarns is questionable since they will not be used to its full capacity.

5.7. Future Work

- Future research should explore in more detail cases where domestic yarns have been preferred instead of yarn coming from offshore sources.

- Future research should be done to study the same factors but applied to technical textiles or high performance apparel, since these are areas in which the U.S. industry is still strong.

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7 APPENDICES

7.1 Appendix A :ASTM Committee D13 on Textiles

This is a selection of the ASTM Standards highly related to the yarns investigated in this research. The list of sub-committees and the complete list of standards under their jurisdiction can be found at:

www.astm.org/cgi-bin/SoftCart.exe/COMMIT/SUBCOMMIT/D13.htm?L+mystore+btfk1314+1206149595

The complete standards can be found in volumes 07.01 and 07.02 of the Annual Book of ASTM Standards (2007).

Sub-committee D13.58: Yarns and Fibers

- D76-99(2005) Standard Specification for Tensile Testing Machines for Textiles
- D204-02 Standard Test Methods for Sewing Threads
- D861-07 Standard Practice for Use of the Tex System to Designate Linear Density of Fibers, Yarn Intermediates, and Yarns
- D1059-01 Standard Test Method for Yarn Number Based on Short-Length Specimens
- D1244-98(2005) Standard Practice for Designation of Yarn Construction
- D1422-99 Standard Test Method for Twist in Single Spun Yarns by the Untwist-Retwist Method
- D1423-02 Standard Test Method for Twist in Yarns by Direct-Counting
- D1577-07 Standard Test Methods for Linear Density of Textile Fibers

- D1578-93(2006)e1 Standard Test Method for Breaking Strength of Yarn in Skein Form
- D1907-07 Standard Test Method for Linear Density of Yarn (Yarn Number) by the Skein Method
- D2255-02(2007) Standard Test Method for Grading Spun Yarns for Appearance
- D2256-02 Standard Test Method for Tensile Properties of Yarns by the Single-Strand Method
- D2258-99(2005) Standard Practice for Sampling Yarn for Testing
- D2259-02(2006) Standard Test Method for Shrinkage of Yarns
- D2260-03 Standard Tables of Conversion Factors and Equivalent Yarn Numbers Measured in Various Numbering Systems
- D2494-02 Standard Test Method for Commercial Mass of a Shipment of Yarn or Manufactured Staple Fiber or Tow
- D2645-07 Standard Tolerances for Yarns Spun on the Cotton or Worsted Systems
- D3108-07 Standard Test Method for Coefficient of Friction, Yarn to Solid Material
- D3412-07 Standard Test Method for Coefficient of Friction, Yarn to Yarn
- D3888-07 Standard Terminology for Yarn Spinning Systems
- D4848-98(2004) Standard Terminology of Force, Deformation and Related Properties of Textiles
- D4849-02b(2007) Standard Terminology Relating to Yarns and Fibers
- D5344-99(2005) Standard Test Method for Extension Force of Partially Oriented Yarn

- D6197-99(2005) Standard Test Method for Classifying and Counting Faults in Spun Yarns in Electronic Tests
- D6587-00(2006) Standard Test Method for Yarn Number Using Automatic Tester
- D6612-00(2006) Standard Test Method for Yarn Number and Yarn Number Variability Using Automated Tester

Sub-committee D13.92: Terminology

- D123-07 Standard Terminology Relating to Textiles

Sub-committee D13.93: Statistics

- D2904-97(2002) Standard Practice for Inter-laboratory Testing of a Textile Test Method that Produces Normally Distributed Data
- D2905-97(2002) Standard Practice for Statements on Number of Specimens for Textiles
- D2906-97(2002) Standard Practice for Statements on Precision and Bias for Textiles
- D3777-97(2002) Standard Practice for Writing Specifications for Textiles
- D4270-95(2001) Standard Guide for Using Existing Practices in Developing and Writing Test Methods
- D4271-88(2001) Standard Practice for Writing Statements on Sampling in Test Methods for Textiles
- D4467-94(2001) Standard Practice for Inter-laboratory Testing of a Textile Test Method That Produces Non-Normally Distributed Data

- D4697-95(2001) Standard Guide for Maintaining Test Methods in the User's Laboratory
- D4853-97(2002) Standard Guide for Reducing Test Variability
- D4854-95(2001) Standard Guide for Estimating the Magnitude of Variability from Expected Sources in Sampling Plans
- D4855-97(2002) Standard Practice for Comparing Test Methods

7.2 Appendix B :ISO Committee TC 38-Textiles: Subcommittee SC 23 – Fibers and Yarns

This is a selection of the list of current standards published by the ISO Textile Subcommittee SC 23 Fibers and Yarns. The standards selected are directly related to the type of yarns investigated in this research.

- ISO 2:1973 Textiles: Designation of the direction of twist in yarns and related products.
- ISO 1139:1973 Textiles: Designation of yarns.
- ISO 1144:1973 Textiles: Universal system for designating linear density (Tex System)
- ISO 2060:1994 Textiles: Yarn from packages: Determination of linear density (mass per unit length) by the skein method.
- ISO 2061:1995 Textiles: Determination of twist in yarns: Direct counting method.
- ISO 2062:1993 Textiles: Yarns from packages: Determination of single-end breaking force and elongation at break.
- ISO 2947:1973 Textiles: Integrated conversion table for replacing traditional yarn numbers by rounded values in the Tex System.
- ISO 6741-1:1989 Textiles: Fibers and yarns: Determination of commercial mass of consignments: Part 1: Mass determination and calculations.

- ISO 6741-2:1987 Textiles: Fibers and yarns: Determination of commercial mass of consignments: Part 2: Methods for obtaining laboratory samples.
- ISO 6741-3:1987: Textiles: Fibers and yarns: Determination of commercial mass of consignments: Part 3: Specimen cleaning procedures.
- ISO/TR 6741-4:1987 Textiles: Fibers and yarns: Determination of commercial mass of consignments: Part 4: Values used for the commercial allowances and the commercial moisture regains.
- ISO 6938:1984 Textiles: Natural fibers: Generic names and definitions.
- ISO 6939:1988 Textiles: Yarns from packages: Method of test for breaking strength of yarn by the skein method.
- ISO/TR 8091:1983 Textiles: Twist factor related to the Tex System.
- ISO 8159:1987 Textiles: Morphology of fibers and yarns: Vocabulary
- ISO 10290:1993 Textiles: Cotton yarns: Specifications
- ISO 16549:2004 Textiles: Unevenness of textile strands: Capacitance method.
- ISO 17202:2002 Textiles: Determination of twist in single spun yarns: Untwist/retwist method.

7.3 Appendix C: 73 Financial and Non-financial Measures

An empirical study of performance measurement in manufacturing firms was conducted by Gosselin (2005), showing that despite the suggestions made in literature, manufacturing companies still put more emphasis on financial measures when designing their performance measurement system, rather than incorporate non-financial measures. A list of the seventy-three performance measurements used to conduct this study can be found in Appendix C

Net profit, gross profit margin, total sales department, amount of raw material inventory, cost per unit produce and others represented the first eleven measures mentioned by the companies that participated in Gosselin's study. The first non-financial measure was the number of worker injuries in twelfth place.

	MEASURE	CATEGORY
1	Net profit	Production Information
2	Gross profit margin	Revenues and Profits
3	Total sales of revenues	Revenues and Profits
4	Profit before tax	Financial Ratio
5	Cost of goods sold	Revenues and Profits
6	Total expenses	Financial Ratio
7	Total costs by department	Financial Ratio
8	Amount of raw material inventory	Production Information
9	Cost per unit produced	Production Information
10	Amount of finished good inventory	Production Information
11	Total operating cash flows	Financial Ratio
12	Number of worker injuries	Employee Data
13	Total net cash flows	Financial Ratio
14	Inventory turnover ratio	Production Information
15	Rate of incidence of injuries	Employee Data
16	Backlog in the delivery schedule	Order and Delivery

17	Number of customer complaints	Quality
18	Account receivable turnover	Production Information
19	Amount of work in process inventory	Production Information
20	Length of time from order delivery	Order and Delivery
21	Materials price variance	Variance Labor & Material
22	Number of units produced	Production Information
23	Rate of production capacity or resources used	Production Information
24	Amount of material scrap produced	Production Information
25	Return on sales	Financial Ratio
26	Number of employee hours	Employee Data
27	Number of units of finished goods in the inventory	Production Information
28	Number of customer orders received	Order and Delivery
29	Rate of incidence of production defects	Employee Data
30	Labor efficiency variance	Variance Labor & Material 31
	Level of absenteeism	Employee Data
32	Number of machine or plant hours used	Non-financial Ratio
33	Return on investment (ROI)	Return on Investment
34	Total of cash receipts	Financial Ratio
35	Number of customer orders completed	Order and Delivery
36	Number of unit of material components in the inventory	Production Information
37	Current ratio	Financial Ratio
38	Total sales per region	Customer and Product Sales
39	Cost reduction resulting from quality product improvement	Quality
40	Total of cash disbursements	Financial Ratio
41	Unit of output per hours of labor used	Non-financial Ratio
42	Total sales per employee	Account Receivable
43	Number and length of down time	Production Information
44	Market share	Quality
45	Cost quality	Quality
46	Return on equity (ROE)	Return on Investment
47	Number of warranty claims	Customer and Product Sales
48	Customer satisfaction: survey ratings	Return on Investment
49	Materials quantity variance	Variance Labor & Material 50
	Labor rate variance	Variance Labor & Material
51	Number of doubtful accounts receivable	Account Receivable
52	Amount of training expenses	Employee Data
53	Total sales per sale representative	Customer and Product Sales
54	Unit of output per machine hours used	Non-financial Ratio
55	Number of new employees	Employee Data
56	Number of employee hours per shift	Non-financial Ratio
57	Percentage of key staff turnover	Employee Data
58	Number of new products	Customer and Product Sales

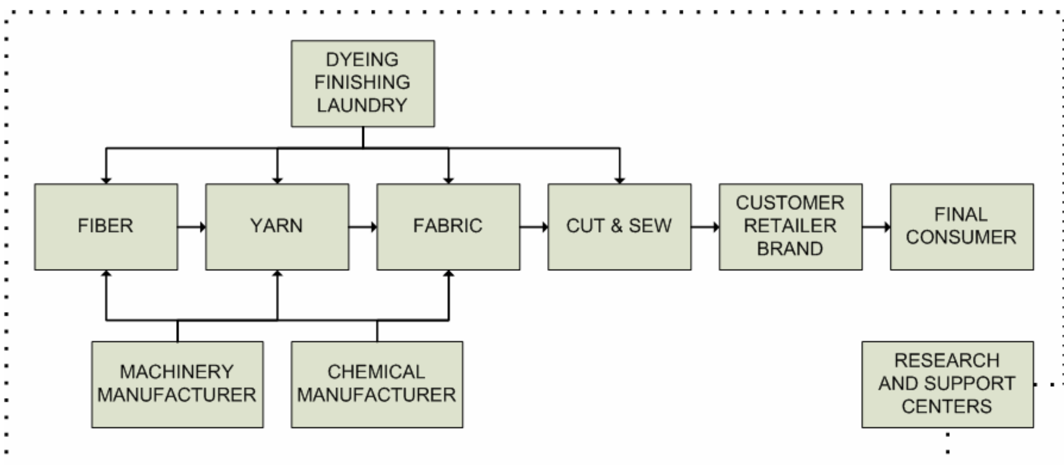
59	Tonnage of production waste produced	Non-financial Ratio
60	Quantity of energy consumed	Non-financial Ratio
61	Number of new customers	Customer and Product Sales
62	Cost per damaged unit produced	Customer and Product Sales
63	Unit of output per unit of raw materials used	Non-financial Ratio
64	Time-to-market for new products	Customer and Product Sales
65	Number of new customer contacts	Customer and Product Sales
66	Earnings per share	Stock Market Measures
67	Average sales order	Customer and Product Sales
68	Number of lines or products	Customer and Product Sales
69	Stock price	Stock Market Measures
70	Unit of output per square foot used	Non-financial Ratio
71	Number of removed products	Customer and Product Sales
72	Price-earnings ratio	Stock Market Measures
73	Rate of products removal	Customer and Product Sales

7.4 Appendix D :Research Questionnaire used to conduct Case Studies

1) Please indicate if your company supplies machinery/yarn/fabric/garments for the following product categories:

Product					
Jeans T-Shirts		Bedding (Sheeting) Hosiery		Sewing Thread	

2) Please mark the links of the supply chain that your company maintains relationship with. Describe the interaction.



3) What are the yarn characteristics commonly specified when selling/buying yarns?

Characteristics		Characteristics		Characteristics	
Type		Elongation		Friction Coefficient	
Count		Hairiness		Presentation	
Content		Evenness		Delivery Time	
Twist		# Neps		Quantity	
Strength		# Splices		Price	

Other:

4) What standard testing methods do you use?

STD METHODS					
ASTM OTROS		AATCC		ISO	

5) Please indicate the yarn property tested, the std method and the equipment used for testing

6) Please list the most important yarn characteristics for the following products. If possible, indicate recommendable spec range and comment how they affect the product.

Property	Jeans	Property	T-Shirts
Property	Bedding	Property	Hosiery

7) Who decides what needs to be specified, your company or your client?

8) Do you use Uster statistics?

9) Do you generate specification sheets?

10) Are these spec sheets available to the customer? Or a modified version?

11) How do you manage the product data?

12) Do you know if you clients use PDM, do they incorporate your specs in theirs?

13) What criteria are used to select suppliers?

14) How to you evaluate the performance of your suppliers?

15) Why do you think your customers prefer you as a supplier?

16) Do you know how your clients evaluate your performance?

17) Could you please mention the most common complaints you receive from your customers?