Chapter 3

The Major Industry Sectors: Fiber, Fabric, Finished Products, and Machinery Manufacturing

Chapter 3

The Major Industry Sectors: Fiber, Fabric, Finished Products, and Machinery Manufacturing

The previous chapter outlined broad themes affecting the industry complex that converts fiber into apparel and other end uses. This chapter will examine the major segments of the industry in greater detail, addressing changes in both production technology and patterns of business organization. The industry will be subdivided as follow's:

1. **Fiber Production:** The process of manufacturing fiber varies greatly, depending primarily on whether the fiber is made of natural or synthetic materials. Synthetic fiber production is closely allied with the capital- and research-intensive chemical industry; the standard industrial classifications (SIC) for synthetic fiber manufacturing are part of the chemical and allied products series, and are not grouped with textile mill products,
2. **Textile Mill Products:** Fabric production is still primarily accomplished with weaving, though knitting and tufting are examples of nonwoven fabrics. The industry is being revolutionized by the shift from shuttle to shuttleless looms, a technology that has been developed primarily by foreign producers.
3. **Apparel (and other end uses):** Manufactured finished products made from textiles are dominated by apparel. In recent years, however, the largest growth in finished products has been in home furnishings and industrial applications. Textiles are being used for a variety of industrial purposes, going far beyond the traditional uses in automobiles. Textiles are now used in high technology medicine, space exploration, erosion control, and highway building. The industries that make finished products are diverse, and include many small firms.
4. **Textile Machinery Manufacturing:** In previous generations, the textile machinery manufacturing sector was the "mover and shaker" behind productivity growth throughout the industry. In recent years, however, few major technologies have been introduced by U.S. firms.

THE PRODUCTION OF FIBER

The fiber sector of the textile industry complex has undergone substantial change in recent years. Synthetic fibers have supplanted natural fibers at a rapid rate. Representing less than 10 percent of the market in 1940, synthetics captured nearly 75 percent by the mid-1980s. Cotton, which made up over 80 percent of U.S. mill fiber consumption in 1940, fell to just over 25 percent by the mid- 1980s.[1] While rayon and acetate represented the only two man-made fibers 50 years ago, today there are thousands of individual products in 10 major classes that can be processed into an almost infinite variety of fabric constructs and styles.[2]

Besides the obvious adjustments in the fabric and apparel industries, the entire structure of the fiber industry has been altered. As synthetics have come to dominate the market, so too have the large multinational chemical companies that are among the major producers of synthetic fiber. With new processes has come a new level of technology and capital intensity as well.

[1] American Textile Manufacturers Institute, *Textile Highlights*, September 1986, p 1

[2] Richard E. Emmert, "The Long View," presented at the 50th Annual Research and Technology Conference, Textile Research Institute, Washington DC, Apr. 3, 1980, p, 1

Background

The fiber industry is composed of the agricultural sector, which supports the production of natural fibers—primarily cotton, but also wool, silk, linen, and jute—and the chemical industry sector, which produces manmade fibers. Most fibers are highly substitutable; not only do manmade fibers compete among each other, but they can substitute for natural fibers.

In 1980, approximately 17 percent of all fibers produced in the world were consumed in the United States; this share fell from close to 20 percent in 1960. Experts believe that the share will continue to fall, reaching 16 percent by 1990. The two major factors responsible for the decline are a marked slow-down in U.S. population growth, along with the substantial industrial progress demonstrated by developing countries.

On the other hand, per-capita fiber consumption is much higher in the United States than in other countries of the world, with a level of 58 pounds per person versus an average world consumption in 1983 of 15.5 pounds per person. But U.S. consumption may have peaked, falling to under 56 pounds per person by 1985;[3] at the same time, world consumption grew sharply. World growth in fiber consumption is a critical factor for U.S. firms to consider as they develop marketing strategies. Of the total growth in world fiber consumption, two-thirds is due to increases in per-capita consumption and one-third from population increase.

Cotton represented a much higher market share of 1983 world fiber production, 48 percent, than of 1983 U.S. fiber production, 25 percent. And yet world production of manmade fibers has shown a growth parallel to U.S. production since the 1940s, and is only today growing faster than U.S. production. The United States is currently the leading world producer of manmade fibers. China is the largest producer of cotton, with the United States being second. Australia is the world's leading wool producer; wool production in the United States is insignificant in the world market, at 1.5 percent of total production.

[3] *Textile Organon*, Textile Economics Bureau, vol. 57, No. 5, May 1986.

Natural Fibers

The major market for natural fibers in the United States is for cotton. It is by far the dominant sector among natural fibers, with over 90 percent of natural fiber consumption and 25 percent of the overall fiber market. Wool and silk are negligible in their overall importance.

Cotton.—Besides the dominant trends of nongrowth in production and a declining share of the fiber market, the market for cotton is unstable from year to year. Major production swings occur due to differences in weather and growing conditions, export demand for fibers, and U.S. economic conditions. Commodity boards of trade provide a market for risk diversification by farmers and cotton purchasers who are unsure of future cotton supply and demand. But weather and changing trade have still kept cotton prices unstable, causing variations in price of up to 50 percent from one growing season to another. For example, large crop yields in the 1979 and 1981 seasons, combined with a slowing of overseas demand for cotton fiber, led to sharply reduced cotton prices in 1982. And U.S. plantings of cotton for harvest in the 1983-84 season were down almost 35 percent, in response to low prices and new government acreage management policies.[4] Nonetheless, the United States remains a major world exporter of cotton; although exports fell off substantially in 1985-86, most forecasts predict a significant recovery for this marketing year. Japan, South Korea, and other Pacific Rim nations are the major purchasers of U.S. cotton, accounting for approximately 60 percent of U.S. exports.

Within the United States, nearly all of the cotton fiber grown and produced comes from the south and west. The top five cotton producing States are responsible for 75 percent of U.S. cotton production. Texas leads with 30 percent of the U.S. total, followed by California with 28 percent, Arizona with 13 percent, Mississippi with 10 percent, and Louisiana with 4 percent. Over 99 percent of U.S. cotton is the Upland variety; the remaining share is American Pima.[5]

[4] "Cotton Monthly Review of the World Situation," International Cotton Advisory Committee, vol. 36, No, 11, June 1983.

[5] *Textile Organon*, vol. 52, No. 1, January 1981, pp. 1-16.

Wool.-Wool production amounts to only 1.5 percent of U.S. mill fiber consumption, most of which is imported. While consumption has been rising in recent years, a growing share of that consumption was made up of imports.

Synthetic Fibers

Without question, the major development in the fiber industry is the growth of the synthetic fibers sector. The first half of the 20th century was marked by the introduction of a large number of synthetic fibers, and the second half of the century by their rapid adoption by consumers. Rayon was the first major synthetic to be produced, starting in 1910. Acetate production began in the 1920s, followed by the production of synthetic nylon and vinyon, as well as rubber and glass, in the 1930s. During the 1940s, production of saran, metallic fibers, modacrylic, and olefin began. During the 1950s, acrylic, polyester, triacetate, and spandex came onto the market. In 1961, production of aramid fibers became commercial; by the mid-1970s, polyester had clearly emerged as the major synthetic fiber in the United States. By the end of the 1970s, polyester led all fibers—including cotton.[6]

In the apparel sector, manmade fibers account for nearly 60 percent of content. Blouses, ski wear, and hosiery are all examples of products that tend to have at least 60 percent synthetic content. For home furnishings, manmade fibers account for nearly 80 percent of content. For industrial textile products, the synthetic share is nearly 90 percent. Production of manmade fibers contributes 30 percent of its output to apparel, 34 percent to home furnishings, and 36 percent to industrial textile uses.

Growth of manmade fiber production and consumption in the mid-1980s is focused on the Third World. The number of manmade fiber-producing plants in the world is increasing, approaching 800 by 1984. The most recent increases have occurred primarily in India, with polyester plants up to 17 in 1984 from 11 in 1983 and nylon plants up to 10 from 8; Pakistan, with polyester plants up to 9 from 5; and Indonesia, with nylon plants up by 4. New fiber-producing facilities that have opened in developed countries since the late 1970s have been more than offset by closings of facilities in these countries. Most fiber industry analysts expect little change in these trends in the future.

The U.S. synthetic fiber industry consists of approximately one dozen large multinational corporations, which are horizontally integrated. Du Pent, Celanese,[7] Monsanto, and Allied are entirely American-owned companies, and rank among the 10 largest world firms. The top 10 producers in the United States account for almost 90 percent of U.S. production. Du Pent, the largest, has far more fiber sales value than its closest competitor, Celanese. Du Pent and Celanese are followed by Allied, Monsanto, Eastman, Akzona, Badische, Hercules, and Avtex. Of the top five fiber companies in 1982, Celanese had the highest fiber sales as a percent of all corporate sales, at nearly 40 percent. If measuring size by corporate sales rather than fiber sales alone, Du Pent remains the leader, followed by Eastman and Monsanto.[8] These companies compete in the markets for six distinct fibers: polyester, nylon, acrylic, polyethylene, polypropylene, and acetate. Because production is mainly performed by the chemical industry—with the exception of Celanese—yarn production is not always counted in the textile industry.

There are two main types of synthetic fibers: cellulosic, which are dominated by rayon and acetate, and noncellulosic, which are dominated by nylon, acrylic, and polyester. Cellulosic fibers are increasingly giving up their market share to noncellulosic fibers.

Cellulosic Fibers. -In 1983, cellulosics represented 7.7 percent of the total quantity of shipments in the manmade fiber market, measured in pounds, and 11.6 percent of the value. These shares marked a major decline from the levels of the early 1970s. In, 1972, for example, the volume share of cellulosic fibers in the manmade fiber arena stood at 20.6 percent; the actual quantity of cellulosics shipped between 1972 and 1983 fell from nearly 1.4 billion pounds to less than 630 million. The real value of shipments during the period also declined, as the 112-percent increase in the current dollar value of shipments was surpassed by an inflation rate of 138

[6]*Manmade Fiber Fact Book,* Manmade Fiber Producers' Association, Inc , 1980

[7]Celanese has recently merged with Hoechst, which may have changed some of these comparisons

[8]*Fairchild Textile and Apparel Financial Director*, 9th and 10th editions, 1982 and 1983

percent over the same time period.[9] These trends have continued since that time, although preliminary estimates from the U.S. Department of Commerce suggest a rebound in 1986 shipments.[10]

The major cellulosic fiber is rayon, which accounts for approximately 60 percent of cellulosic shipments. Rayon, a regenerated cellulose product, was the first manmade fiber patented. It was discovered in 1855 by Audemars, a Swiss chemist. The cellulose source for his product was the fibrous inner layer of the mulberry tree. Until 1924, rayon was called artificial silk. The first commercial production of this material was by the Frenchman Chardonnet, who became known as the father of the rayon industry. The first U.S. plant producing rayon was the American Viscose Corp., which opened in 1910. There were four rayon-producing plants as of 1983, down from 26 in 1950.[11]

The other large category of cellulosic fibers is acetate and acetate derivatives. Acetate, also a regenerated cellulose, was first commercially produced by Celanese in 1924. Production was halted temporarily during the Depression. As of 1983, there were five acetate-producing plants operating in the United States.

The major end uses of cellulosic filament yarn are for products of the apparel industry, though some home furnishing and industrial uses are also important. Six product categories using cellulosic yarn account for about 80 percent of consumption in the United States. These six categories are, in descending order of magnitude:

1. fabrics for lining apparel;
2. robes and loungewear;
3. drapes and upholstery;
4. topweight fabrics;
5. tires; and
6. underwear, nightwear, and bras.

All of the categories show a decrease in consumption of this yarn type in recent years, as other fibers continue to make inroads.

[9] "Manmade Fibers," "Apparel," *U.S Industrial outlook, 1984,* pp 40-5 to 40-8, 41-1 to 41-5,

[10] *U.S. Industrial Outlook*, 1987, op. cit., p. 41-4.

[11] *Manmade Fiber Fact Book*, op cit.

[12] Ibid.

[13] *Textile Organon*, vol 54, No. 9, September/October 1983

The major end uses of cellulosic staple fibers are dominated by products of the industrial sector, with over 30 percent of the fibers used by the medical, surgical, and sanitary category for disposable items. The top six major uses of cellulosic staple fibers account for about 82 percent of total U.S. consumption. These six categories are, in descending order of magnitude:

1. medical, surgical, and sanitary;
2. drapery and upholstery;
3. topweight fabrics;
4. miscellaneous industrial-type products;
5. bottomweight fabrics; and
6. sheets and other bedding.[14]

From 1976 to 1982, actual consumption of all fibers in these six categories declined by about 25 percent. The major declines in use were 57 and 39 percent, in the drapery and upholstery and the medical, surgical, and sanitary categories, respectively—in contrast to an increase of 18.8 percent for the other five categories as a group.

Noncellulosic Fibers.— Noncellulosic fibers represent the growth segment of the fiber industry. This segment is dominated by nylon, acrylic, and polyester. While noncellulosics are manufactured from a variety of products, petroleum is the predominant raw material in this sector. Between 1972 and 1983, the quantity of noncellulosic fibers shipped grew by 40.6 percent, with the value of shipments exceeding the inflation rate.[15] Noncellulosics also represent an area of significantly growing exports, with the value of shipments more than tripling over the period—from less than $200 million in 1972 to nearly $775 million in 1983.

Nylon 6,6, invented by Carothers in 1931, was first produced commercially by Du Pent in 1939. A nylon salt, produced through chemical processes, would "polymerize' '-the small molecules were linked up to form long, chainlike molecules. This thick, syrupy material would then be hardened by a shower of water, chopped into flakes, melted again, and forced through the fine holes of a spinneret to form filaments of yarn. Nylon was introduced as a "miracle" fiber, which performed well in such diverse products as sewing thread, parachute fabric,

[14] Ibid.

[15] Ibid., vol. 55, No. 3, March/April 1984, p. 35.

and women's hosiery. Its use became widespread in military applications during World War 11, as a replacement for other materials used in tires, tents, ropes, and other defense supplies. At the conclusion of the war, 80 percent of the fiber consumed in the United States was still cotton, with manmade fibers, silk, and wool accounting for the remaining 20 percent. In the early 1950s, nylon became popular in carpeting and automotive upholstery, further increasing the manmade market share of fibers.

Because nylon is the major fiber used in carpeting and the demand for carpeting is largely determined by construction, the severe and cyclical curtailments in the construction industry were the chief reason for a decline of 11.1 percent from 1979 through 1983; by 1985, however, rug shipments had nearly recovered to their 1979 level. Noncellulosic fibers introduced in the late 1940s included strong metallic fibers by Dow Badische, modacrylic-a flame-resistant variation of acrylic-by Union Carbide, and olefin—a light fiber used for such items as boat ropes, since it floats in water—by Hercules. In recent years shipments of olefins have increased dramatically–by 80 percent between 1975 and 1983. Acrylic was introduced in 1950 by Du Pent as a manmade substitute for wool. A few years later the first wash-and-wear product was marketed, with fiber composition of 60 percent acrylic and 40 percent cotton.

Polyester, which is a petroleum-based fiber, was first produced in the United States by Du Pent, and in the rest of the world by Imperial Chemical Industries, in 1983. It dominates the manmade fiber market and accounts for over 40 percent of the market share, and over 28 percent of the market for all natural and manmade fibers. Despite its continued dominance in the field, polyester has experienced recent drops in total shipments–7.9 percent from 1979 to 1983. During the rest of the 1950s, research efforts into manmade fiber production turned from the development of new textiles to the modification, diversification, and commercialization of existing products. In the 1960s, spandex was introduced to the United States as a lightweight, highly extensible fiber. This was followed by the introduction of aramid, a lighter fiber but one that is tougher than steel.

In 1982, the top 12 uses of noncellulosic filament yarn accounted for over 85 percent of noncellulosic yarn sold in the United States. The 12 major end-use categories, representing a mix of apparel, home furnishings, and industrial uses were, in descending order of magnitude:

1. carpets and rugs;
2. electrical and reinforced plastics;
3. bottomweight fabrics;
4. tires;
5. miscellaneous industrial-type products;
6. rope, cordage, and fishline;
7. topweight fabrics;
8. underwear, nightwear, and bras;
9. retail piece goods;
10. drapery and upholstery;
11. industrial narrow fabrics; and
12. sheer hosiery.[16]

The single category of carpets and rugs consumed over 20 percent of the noncellulosic yarns sold in the United States, with industrial uses dominating the remaining large users. From 1976 to 1982, the largest declines were found in the apparel categories, as imports and a switch to natural fibers moved bottomweight, topweight, and retail piece goods fabrics away from the noncellulosic fibers.

The category of carpets and rugs dominates the noncellulosic staple fiber uses, consuming over 25 percent of these fibers. There are 12 major categories of noncellulosic staple end uses. They are, in descending order of magnitude:

1. carpets and rugs;
2. bottomweight fabrics;
3. topweight fabrics;
4. fiberfill, stuffing, and flock;
5. sheets and other bedding;
6. retail piece goods;
7. drapery and upholstery;
8. craft and handwork yarn;
9. sweaters and related accessories;
10. medical, surgical, and sanitary;
11. anklets and socks; and
12. unallocated industrial nonwovens.[17]

The apparel categories of bottomweight and topweight fabrics, along with sheets and retail piece goods, consume large quantities of noncellulosic staple fibers, primarily as a polyester staple in the production of blended fabrics. The top 12 end uses of

[16]Ibid , 1,01. 54, No 9, September/October 1983.
[17]Ibid

noncellulosic staple fiber account for over 80 percent of the fibers consumed in the United States, with the largest single increase coming from medical, surgical, and sanitary use.

Technological Innovations

Innovations are occurring throughout the specific industry segments involved in yarn formation. Machines using new technology are capable of providing a four- to five-fold increase in productivity with respect to open-end spinning, and about a twentyfold increase with respect to ring spinning. In addition to innovations already being adopted, this section will review innovations that are pending or needed in fiber production.

Innovations in Specific Areas of Yam Formation

Texturing. -Innovations in texturing have stimulated growth in the knitting sector. The ability to have heat set a crimp in synthetic fiber provides additional and desirable bulk to the fiber.

Opening and Picking of Cotton. -Traditionally, a bale of cotton had to be separated manually into layers and fed into hoppers, where the cotton was tumbled to break it into small tufts and to mix the cotton from various bales. The material was then transported, either by belt conveyor or through pneumatic ductwork, to pre-openers or cleaners, in order to reduce the tuft size and remove some of the nor-dint material. If the cotton was to be blended with other materials, such as synthetic fibers, additional hoppers similar to opening hoppers were used. Waste from the hoppers was manually removed. The next step was the production of a partially cleaned, flat, even sheet, in a roll, which was then hand-fed to the next stage, carding.

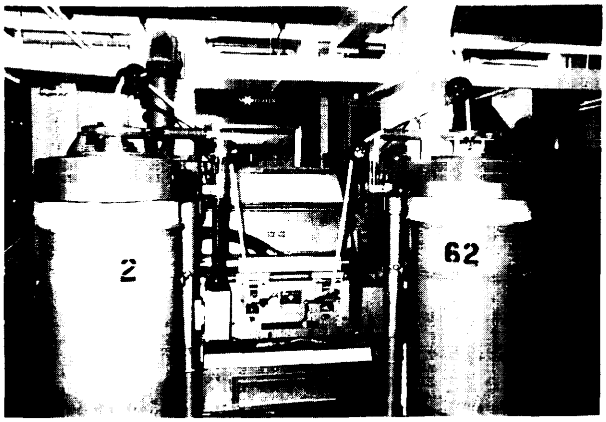
New technology in opening, cleaning, and picking has led to substantial automation of the process, increased productivity, improved product quality, and an enhanced work environment. Automatic bale plucking systems have been known to the industry since the mid-1960s, but their incorporation into the production process has just recently gained momentum. The carousels and automatic feeders, which pick off of several bales at once, have the following advantages:

- faster picking,
- a more intimate blend of cloth, since carousels can pick off of several bales of cotton at once,
- bypassing the manual picker, which eliminates the related back-breaking work, and
- eliminating some of the dustiest work of the production process.

Carding Cotton.—The purpose of carding is to further separate the fibers from the bits of leaf, trash, and short fibers, to straighten or parallel the cotton fibers, and to forma soft, untwisted, ropelike material called sliver. Carding is accomplished by bringing fibers over a feed plate to a feed roll and a cylinder covered with wire teeth, called the licker-in. The licker-in rotates rapidly over the lap of cotton held by the feed roll and gradually opens the tufts of cotton in the lap. As the tufts are opened, dirt and trash fall out. As cotton is processed by the card, fibers collect between the wires of fillet card clothing—consisting of fabric and wire—and must be stripped away traditionally by hand. Carding has traditionally been the source of greatest cotton dust exposure for workers, especially for strippers.

New carding technologies, especially chute-feeding systems, have been available since the 1960s, but their adoption in the textile industry accelerated only recently. The use of chute-fed cards encloses the process and removes the necessity for manual carding and for most manual cleaning. At least 11 production advantages result from the use of new carding technology:

1. elimination of doffing and racking;
2. elimination of the manual transport of materials to the card room, and of hanging the material onto cards and later into feed rolls;
3. improvement in yarn, since the automatic process on feed rolls reduces heavy places in the yarn;
4. more than doubling of speeds, in some cases by using metallic-clothed cards instead of flexible cards;
5. improvement in card settings due to roller bearings on cylinder supports, which allow for adjustments leading to more even clothing with closer tolerances;
6 better integration of fibers, resulting in a more uniform and stronger piece of yarn with improved sliver CV and weight variation;



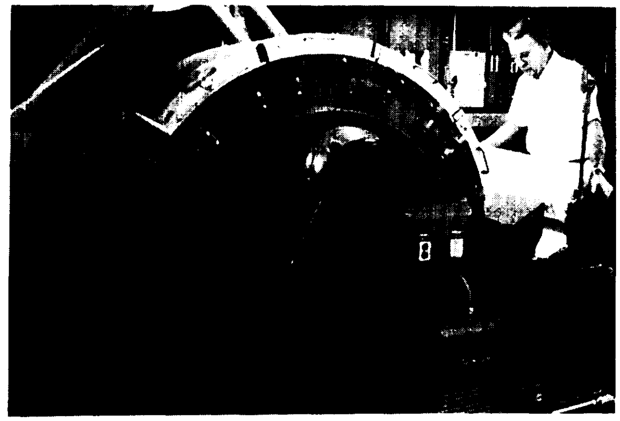


Photo credit: Charles Gardner. School of Textiles North Carolina State University

Pictured on left, a high-speed chute-fed carding device; on right, its technological predecessor, the lap-fed card.

7. improved spinning performance, due to sliver improvements, meaning fewer ends down;
8. reduced requirements for floor space;
9. reduced labor turnover by eliminating undesirable lap-laying tasks; and
10. reduced dust exposure due to enclosure of cards, and because hand cleaning of cards traditionally done twice a day can be reduced to once a week.

Spinning.—Spinning is the process by which fibers become yarn. The purpose of the spinning process is to stretch the sliver to its final diameter, and to insert the desired amount of twist. Thus, the yarn acquires its necessary strength. The traditional spinning method is called "ring spinning. " In ring spinning, bobbins are hung in a creel and ends are individually fed into drafting rolls. The twist is imparted by passing the yarn through a traveler on a ring while it is being wound onto bobbins placed on a revolving spindle. Fine trash and short fibers are often released into the air during this process.

Spinning has traditionally been labor-intensive, accounting for anywhere between 50 and 70 percent of all yarn manufacturing labor costs. More specifically, costs of spinners and doffers would amount to 50 to 80 percent of spinning labor costs, with high labor costs focused on cleaning, piecing, doffing, maintenance, and transportation.[18]

There has always been a strong impetus to try to reduce labor costs with the installation of more modern equipment—especially equipment that reduces ends down and repairs broken threads automatically. By the mid-1960s, a new technology called open-end spinning became commercially available. In open-end spinning, the open-end frame is supplied with sliver from a draw frame, eliminating the need for a roving frame; passes sliver through a drafting system into a centrifugal rotor; and creates a wound package, eliminating the need for a subsequent winding operation. When open-end spinning is installed to operate from sliver through winding, the number of conventional processes is reduced, thereby significantly contributing to an automated system.

Other advantages of open-end spinning, when applicable, include:

- increasing the production rate by four to five times that of the ring spindle;[19]
- the ability to process a far lower grade of cotton than ring spinning;
- reducing cotton dust exposure by enclosing the process and being more adaptable, which alleviates the need for local exhaust ventilation; and
- reducing the noise level in spinning rooms.

[18]Dan S Hamby (ed.), *The American Cotton Handbook*, 3d ed (New York Interscience Publishers, 1965), p. 374.

[19]Centaur Associates, Inc., for OSHA, "Technical and Economic Analysis of Regulating Occupational Exposure to Cotton Dust, " vol. I, January 1983, p. 3-48

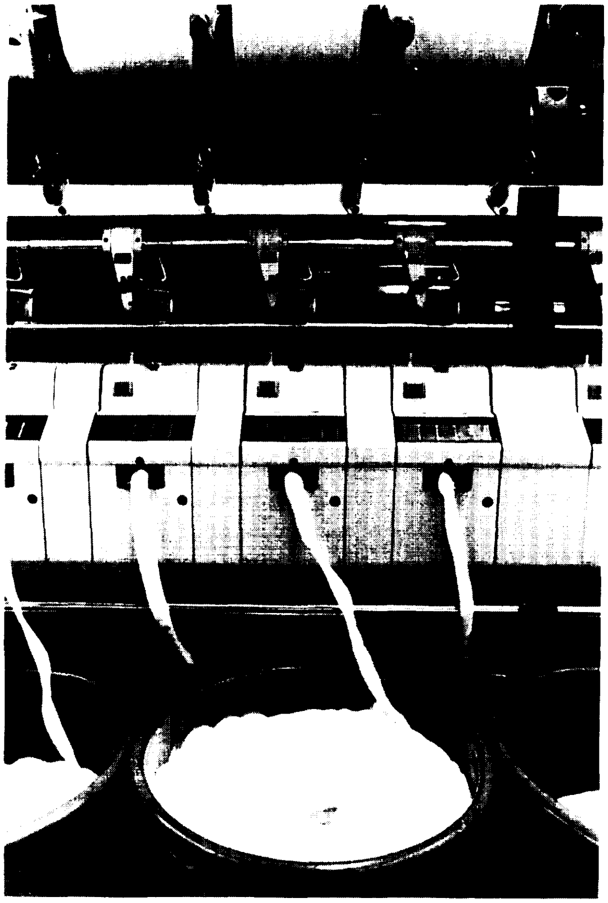


Photo credit American Textile Manufactures Institute

Open-end spinning was introduced in the mid-1960s. It represented an improvement over ring spinning in terms of yarn quality, productivity, and safety.

There have also been innovations in spinning attachments. Automatic doffing (unloading) machines reduce unit requirements for doffer operators. Automatic devices for piecing (tying) broken yarn reduce unit requirements for spinners.

Winding.—Loading, or automatic creeling of machines with automatic tying-in of yarn ends, reduces unit requirements for operators, Integration of filling winding with weaving eliminates separate processes and associated handling.

Pending Innovations in Yarn Formation

In general, the ideal yarn manufacturing process would take fiber from a bale, convert it to a sliver, and move it to a spinning process—such as open-end spinning—with automatic transfer of the yarn output either to a warper or a loom. Emphasis would also be placed on computer monitoring of both quality and production rate, with the quality monitoring being tied to appropriate feedback and control mechanisms. The monitoring technology is already available for drawing, and technology for monitoring either open-end yarn or other kinds of yarn is on the horizon.

Another area of considerable importance with respect to monitoring is the ability to determine the need for machine maintenance by continuous monitoring of yarn production. This requires that all ends be monitored continuously, and that faulty positions be identified immediately. The repair, when it is needed, could be made automatically, or that end could be stopped and machine maintenance ordered. A useful system would also monitor and record long-term gradual deterioration, as opposed to short-term problems. The goal of the system would be to prevent the manufacture of defective material.

In general, it is important to measure and control quality at every step of the yarn formation process. Adequate computer technology is already available; the real problem seems to be the development of appropriate sensing elements.

There are a number of opportunities in the present yarn process for automated materials handling, including the use of robots. This is particularly true for systems that have reduced the number of process steps, such as open-end spinning, but it could also be used with ring-spinning technology, in which the automation of roving frames is a current need. Connecting winders to large spinning frames is a potential development, but winders need to be designed to accommodate some flexibility of yarn count. This could perhaps be accomplished by designing winders with space for extra positions. Such a linking technique would allow less handling of yarn packages—a distinct advantage, since it would also allow better package identification and control.

Although techniques for the continuous monitoring of various stages of yarn processes are available, knowing where to direct that information or what corrective actions to take is still largely unknown. Since it is necessary to be able to identify abnormal parts of the process, the real issue is to determine where in a process faults occur, what their interrelations with other process steps will be, and what feedback loops are needed to exercise control.

There is potential for the automatic analysis of incoming bales of fiber, particularly if robots or other automatic devices that could direct the bale to the appropriate storage area could be involved in the analysis. Automated bale storage is a labor-saving technology that leads to less handling, as well as presenting the opportunity of coding each bale for future identification. This is important because of the desirability of tracking the identity of the material in each textile process, from the initial bale through the final step. This, in turn, allows one to know the accurate history of all material and all processes, and allows for solutions of quality control problems based on more complete information.

Development of New Fasciated Yarn Systems.[20] —Du Pent developed a fasciated yarn system in which there is never an open end, and there is a continuous strand from the core drafting system through the twister to the wind-up device. In the Du Pent system, fibers on the outside of the yarn have a different helical pitch to the fibers in the core of the yarn. An extreme case of this type of yarn structure occurs when the core fibers have no twist and the sheath is wrapped helically around the core, causing the whole structure to cohere. Developing from the Du Pent system, it becomes possible to contemplate laying fibers onto false-twisted yarn, with a fiber laid parallel to the axis of the yarn and anchored there, becoming a wrapper after it passes out of the false-twist zone. A stream of fibers landing on a false-twisted core creates a fasciated yarn having a twisted sheath, but a virtually twistless core. Alternatively, fibers can be raised from the surface of the yarn and then laid over the false-twisted core to produce similar effects. Fasciated yarn systems tend to prevent inter-fiber slippage.

Alternatives to Rotor-Type Open-End Spinning.-There has been considerable interest in alternatives to the rotor-type open-end spinning system. Pavek's rotating needle basket was used to capture fibers and consolidate them at the open end of a forming yarn. Goetzfried and others were interested in air-vortex systems, in which a helical or circular yarn end rotated inside a stationary tube and the yarn motion was caused by an air vortex. Fibers were injected into the tube and laid on the "open end. " The major difference between these systems and the ones known today is the way in which the arriving fibers are brought into contact with the departing yarn. The common feature is that all these cases have an open end to the forming yarn.

Development of Mixed Systems.—It is possible for arriving fibers to be false-twisted into a core onto which a sheath is deposited. If the core is discontinuous with the core fiber supply, then the system is an open-end system. It can also be a fasciated system, by virtue of the sheath fibers which are laid onto false-twisted ones,

Emergence of New Twisting Systems.—Whereas conventional machines use a relatively massive rotating component to put in "twist, " such as a ring spindle, a flyer, or a rotor, a new systems feature is for the twisting medium to act directly on the surface of the yarn. Where metal surfaces are used, it is possible to create a pair of counter-surfaces acting on a yarn. The frictional forces acting on the yarn surface create a torque which generates twist. Alternatively, fluid friction can be used. The most common of these latter types is an air-vortex, which can readily be made to rotate at extremely high speeds; the fluid friction creates the torque in the yarn.

Creation of New Yarn Structures.—Earlier experience with open-end yarns has shown that the disorderly sheath structure, with its tight wrapper fibers, causes a harsh hand and weakness, which have been major causes restraining growth of the open-end spinning system. These problems are being solved in some new machines through differences in the sheath fiber orientation.

Needed Innovations in Yarn Formation

While many innovations are being brought to yarn formation, more are envisioned. At least eight general technological developments are needed in the process of yarn formation, according to a study by the American Textile Machinery Association (ATMA):

1. higher speeds, better quality, universal systems in spinning;
2. uniformity monitoring in carding;

[20] Two major ideas are involved in making fasciated or Wrapped bundle yarns 1) the efficacy of using a wrapping filament or fiber to create fiber cohesion in an untwisted staple fiber bundle; and 2) the fact that when a fiber or part of one is laid on a false-twisted bundle, the laid-on fiber becomes a wrapper when the false-twist is removed

3. overall process consolidation;
4. automation, in process and quality control;
5. fewer steps in manufacturing;
6. sizing in the spinning and winding processes;
7. on-line analysis of the trash content of cotton; and
8. emphasis on friction spinning, with ring spinning becoming obsolete.[21]

The advent of the Murata air-jet spinning system and the Fehrer and Platt friction spinning systems have heightened interest in new forms of manufacturing staple yarns. Fehrer, Schlafhorst, and Suessen are working on a different friction spinning system, and Toyoda, Howa and others are working on different air-jet systems. It is believed that higher delivery speeds will become common, and that there will be different count ranges for each of the different systems. Air-jet and friction spinning will likely fill a gap left by rotor-type, open-end spinning.

Industrial Structure

During 1985, domestic fiber output fell significantly. Even though cotton fabric shipments rose nearly 9 percent, manmade fiber domestic shipments dropped by 19 percent, and woolen fabric shipments from U.S. mills fell by 21 percent.[22]

As with the entire textile industry complex, one of the most important single factors influencing the economic future of the fiber sector is imports—both fiber imports, which compete directly, and fabric and apparel imports, which compete by reducing domestic demand. A positive balance of trade still exists in all synthetic fiber categories except cellulosic yarn and monofilament, but this surplus has shown substantial decline.

Between 1979 and 1985, developing nations were busy increasing their production of fiber. The growth was especially significant in noncellulosics, with China increasing its production over that period by 361 percent, India by 203 percent, and Indonesia by 102 percent.[23] China expects self-sufficiency in manmade fibers by the year 2000.[24] During the same period, U.S. production of noncellulosic fibers lost world market share, from nearly 33 percent to 23 percent. In addition, cellulosic fiber production in the United States fell from 12.5 percent of world production in 1979 to 8.4 percent in 1985. U.S. employment in manmade fiber production during the decade from 1975 to 1985 fell by 41 percent—more than 40,000 jobs.[25]

Natural Yarns

The fiber sector of the textile industry consists of both large integrated corporations and small flexible units that compete and trade with each other. The rivalry among producers is high, and there are an especially large number of competitors in the cotton yarn industry; there were approximately 270 firms in the industry through the 1970s. The concentration of the cotton industry is low and stable, at a level of 20 percent.

The cotton and wool yarn markets are characterized by low growth, making an expanded market share dependent on taking markets away from competitors. The different yarns are easy substitutes. The biggest problem in this sector is competition from manmade fibers, comprising 10 perfect substitutes for natural fibers. The resulting intense competition reduces profit margins. Cotton and wool yarn prices have experienced large decreases due to competition with synthetics.

Technology for natural fiber is largely supplied by a few machinery producers, of which none are U. S.-owned. The development of this machinery is only done by machinery producers. The turnover of machinery is frequent, making the technology used an important factor in competition. Productivity increases with new technology are high.

There is no potential threat from the suppliers to integrate forward, toward end use of the product; the agricultural and textile industries are too different, and their interests are on different levels. But there is a threat of backward integration by fabric producers. Yarn costs play a large part in the buyer's industry, yet the buyer's bargaining power is high. The reason for high bargaining power is that different yarn types are competitive, and the sector is characterized by frequent overcapacity.

21 American Textile Machinery Association, "Needs Identification" Annual Meeting Report.
22 *Textile Organon*, vol. 57, No. 8, August 1986.
23 Ibid., vol. 57, No. 7, July 1986.
24 Ibid., vol 57, No. 3, March 1986
25 Ibid.

Entry and exit barriers into the industry are a question primarily of capital cost. Industries with the necessary financial resources can easily enter the spinning industries. Inexperience can be easily overcome with new technology, which is available in abundance.

Large-scale operations seem to have a competitive advantage in being able to reduce overall raw materials costs by purchasing large quantities. A key to achieving cost advantage is buying cotton at the right time. Cotton prices are largely a result of supply and demand in the U.S. commodity exchanges. As a result, cotton spinners try to buy cotton in large quantities at preferential prices; this, however, leads to large inventory costs. The more vertically integrated firms have a slight advantage in this competition, especially when the large firms are also their own suppliers and can add to the end-product stage. Competitive position depends heavily on the relative importance of yarn production in the overall enterprise.

On the other hand, there is some offsetting cost advantage for the smaller firms because of their higher flexibility in production. An example is Tuscarora Mill, a specialized yarn producer that carries a wide assortment of yarns. The success of the company lies in constantly finding market niches with high margins. Industry experts believe that flexibility of small firms will allow them to become more dominant in the marketing sense, which will create more small and flexible firms within the industry.

A strong future for the U.S. fiber industry will likely require a reduction in production overcapacity, and on emphasis on out-innovating competitors—not in basic fiber production, but through specialized. products. The industry will shrink and become more competitive. Profits are likely to be low, unless some cooperation with the textile and apparel sectors of the industry is accomplished through vertical integration. Observations from machinery expositions indicate that small and flexible fiber production units are in demand by textile companies.

Synthetic Fibers

The synthetic fiber industry is characterized by similar manufacturing processes, easy substitutability of products, similar markets, and similar expenditures in R&D. Texturizing and twisting, which add to the desired quality of synthetic yarns, are two processes that distinguish manmade yarn production from natural fiber manufacturing.

Fiber shipments for some companies constitute a large amount of their total shipments. In 1974, Celanese had 50 percent of its business in fibers, and Avtex 100 percent. All other large chemical companies have a fiber business that is less than one-third of their total shipments. Major fiber firms have been reducing their dependency on fibers, with the exception of Badische.

Fiber markets are nearly saturated, and there currently is a problem of overcapacity; these markets depend largely on the apparel market, and U.S. apparel markets have suffered from severe import penetration. The two major fiber markets are the commodity market and the specialty market, each of which has its own distinct characteristics. While the United States is strong in the development of specialty fibers, its main outputs are commodity fibers.

Suppliers to the fiber industry provide raw materials and technology, and do research and development. Some fiber companies operate their own refineries; others must make purchases from competing multinational chemical companies.

There are substantial entry and exit barriers. Entry barriers in the fiber industry are a function of:

- large economies of scale,
- low product differentiation,
- *low* cost advantages,
- high capital requirements, and
- limited access to distribution channels.

Suppliers of the fiber industries have the potential of entering the industry. But fiber producers are unlikely to have the necessary resources to integrate backwards, into an even more capital-intensive industry.

Technology for the synthetic fiber industry is largely supplied by a few machinery producers, of which only a small percentage are U.S.-owned. The development of this machinery is done primarily by machinery producers. Updating of machinery is fairly frequent, so that the technology used is an important factor in competition, but is one over which most firms have little control. Some of the technology, however, is developed by fiber producers who keep proprietary rights on the developments.

The Throwing, Winding, and Thread Processes

The throwing, winding, and thread industries consist of a few specialized firms—some vertically integrated, mostly throwing and winding, and some independent corporations, mostly thread—which compete in intermediate markets in the textile industry. Many of them are jobbers that serve the fabric-producing industries. They are defined by their similar manufacturing technologies, their similar distribution channels and markets, and their high capital expenditures for plant and equipment.

The throwing and winding industries (Standard Industrial Classification (SIC) 2282) and thread industry (SIC 2284) have similar technologies, but their structures are quite different. Throwing and winding firms face competitive forces similar to those of the spinning industries. The thread industry on the other hand, is characterized by its distinctiveness and flexibility. Both industries have high profitability but declining productivity.

Technology turnover is high in throwing and winding operations. Expenditures for new plant and equipment are primarily by large-scale operations. In contrast, the thread industries increasingly consist of small locations where little is spent for new machinery.

Throwing and winding represent mature industries that compete on a cost basis, and machinery replacement tends to replace labor. The industry is characterized by increasing concentration and high imports. But due to high profitability, imports are decreasing while exports are increasing.

The number of companies in the thread industry is low. All are highly specialized, serving their individual markets. Most of these companies are small and flexible. They are able to serve markets quickly, and to produce small amounts efficiently. The specialization of their service gives these companies an individual touch, especially in volatile markets where demand depends largely on the current quality behavior of the customers. Most of these companies are not diversified, and threads are their only products. Expanding market share is possible with an expanded product line, and it is relatively easy due to the low number and specialization of competitors. There is low standardization among producers; competitors can be distinctively different and unique.

Costs are a less competitive force in this industry. Profit potential is high, due to a favorable structure marked by high product specialization and low cost competition. Profit potential in the industry is also enhanced because entry barriers are only moderate, being a function of flexibility, capital requirements, and product specialization, and because exit barriers are low, since most of the machinery depreciates in a short time period. Profitability in the thread industry is largely determined by:

- the relative importance of the thread process in overall yarn production,
- the relatively low bargaining power of these corporations against their suppliers,
- the price consciousness of their customers, and
- low barriers of entry and exit—especially the forward integration of the yarn industries.

The thread industry is still in a growth period. Exports are increasing rapidly, and imports are at low levels. Employment has actually increased, and these small companies benefit from their flexibility in the marketing sense. One might expect that the small thread firms would form excellent cash cows for larger textile corporations, especially spinning industries which buy thread. As long as thread producers maintain their uniqueness, however, their solid bargaining position will make vertical integration less likely to occur.

General Prospects for the Fiber Industry

The U.S. fiber industry is in the middle of massive structural change. Part of the current situation is caused by the technological maturity of the whole fiber-textile-apparel industry complex. Part is due to the shift from natural to manmade fibers. And part is caused by an erosion of the competitive base of the United States as a place for production, even for capital-intensive industries.

The U.S. fiber market is mature and saturated. Massive overproduction has depressed prices in a low growth market. High investments in machinery, aimed at gaining a competitive edge by means of productivity and a reduction of costs, have not yet resulted in satisfactory returns.

Furthermore, one can observe a drastic change in international fiber production. The Far East—

especially South Korea, Taiwan, Japan, and China—is expanding fiber production, and may soon exceed the production level of West Germany. These countries are expanding their production in areas that western countries once dominated. The plants under construction in many developing countries indicate that these countries use the fiber industry to gain a niche in international markets, and not simply to satisfy their own demand for textiles and apparel. Most projects are financed by western banks, and the technology is usually sold by European countries.

With the exception of Japan, fiber producers in developing countries are following the strategy of competing in basic fibers on a cost basis. Japan, on the other hand, produces high quality and highly specialized fibers for export. The success of these strategies is evidenced by the growing import penetration of fibers into the United States.

U.S. and European fiber producers' strategies to counter these trends in international markets have been diverse and, more or less, successful. The most apparent move is to reduce dependency on low-cost fiber producers, as is being pursued by Du Pent, American Enka, and Rhone Poulenc. These companies are also establishing production facilities in developing nations, to overcome the political trade barriers that sometimes prevent access to overseas markets.

The big American fiber companies are still trying to compete on a price basis with imports, whereas in European countries there is increasing emphasis on specialization and service. One can expect that it will be some time until U.S. fiber producers change their strategies of high volume and standard fibers, since most developing countries produce the same fibers.

TEXTILE MILL PRODUCTS

Like the fiber sector of the industry, fabric formation has undergone changes in both technology and business structure. New weaving machines have been responsible for increasing the speed of production and the quality of the product, while at the same time improving the work environment. Because of the high cost of new machinery, adoption of the new technology has been primarily by the largest and most profitable companies. New economies of scale have caused mergers and consolidations, the building of new plants, and the closing of old ones. While the textile mill sector of the industry leads U.S. manufacturing in productivity increases, it has been hit by a flood of imports that threaten profits and even survival.

Background

The textile mill products sector of the textile industry includes all operations that are involved in converting fiber to finished fabric and the production of many nonapparel consumer products. The health of the U.S. textile mill production is clearly affected by the health of the U.S. apparel sector, with some estimating that loss of the apparel sector would almost certainly doom 35 percent of the domestic textile industry.

The textile mill products sector is the tenth largest industrial employer in the United States, with approximately 700,000 people—86 percent of whom are production workers. Shipments total over $50 billion annually. The industry is characterized by substantial productivity increases but sagging earnings, increased capital investment but declining employment, and plant expansions as well as plant closings.

The largest textile company in the United States is Burlington Industries, followed by Stevens and Milliken. Other major textile manufacturers are West Point Pepperell, Springs Industries (which has now acquired Lowenstein, on its own a major producer), Dominion Textiles, Collins & Aikman, Cone Mills, United Merchants & Manufacturing, Dan River, Fieldcrest, and Riegel. The top 12 publicly held U.S. textile mill companies produce approximately 26 percent of total sales dollars. The typical large public textile company showed a 10-year average return on sales of about 3 percent, and a 10-year average return on equity of about 9 percent.

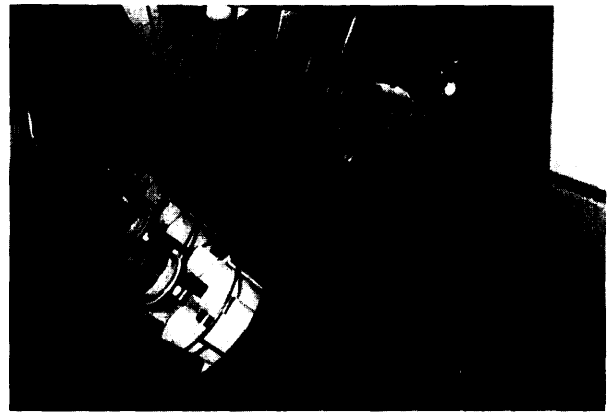
The Traditional Production Process

The major traditional production processes for woven fabrics are winding, warping, slashing, weaving, and finishing. In addition, there is fabric that is knitted or manufactured using other nonwoven techniques.

Winding.—The output of spinning machinery is spindles of short-length yarn. These spindles cannot be used in the next production process because they are of unequal length, because there is not enough yarn on a spindle, and because the spindle size is unsuitable for the weaving and knitting processes. For these reasons yarns must be rewound onto large packages suitable for the appropriate production process. Weaving requires a different package than knitting. These different requirements for the next processes make a uniform winding process almost impossible. Low-quality yarns perform badly in winding, and weak spots in yarn are detected through yarn breakage. Recently, most winders have been equipped with automatic splicing devices to prevent the knots that can enter yarn from repair of breaks. These splicing machines detect a break problem, pick the two ends up, and splice them together. Such devices decrease the labor intensity of the process, as does automatic feeding of the individual winding positions.

Warping.-The warping process produces the “warp” threads for weaving, which run lengthwise. The goal is to reach a very high density of yarns on the beam for the warp; 400 to 700 yarns are wound onto the beam at once. This is done at a high speed, with great attention given to the tension of the yarns. A frequent problem is the uneven length of the yarn on the packages. The more precisely the winding process is performed, the fewer the unused yarns left over in the warping process. Still, the warping process is time-consuming. The packages are manually put onto a frame, where the yarns are guided through a reed, which separates the individual yarns and ensures that they stay parallel.

Slashing. -Four to six beams are run together on a slasher to achieve the correct density and amount of yarns on the warp beam. Yarns receive a protective coating that shields them from excessive abrasion during the weaving process. Without this treatment, most yarns would not stand the constant friction and tension; the result would be frequent end breaks, with an associated decrease in productivity. The “chemistry” used in the slashing process is confidential in every weaving plant, due to the significant differences it can account for in the efficiency of the weaving process.



m m

Weaving.—Weaving transforms yarn into fabric by interlacing lengthwise warp yarns and widthwise filling yarns at right angles. A warp is planned for several pieces of fabric, which are usually about 300 yards long. To keep the efficiency of weaving plants high, changes in the warp on the loom must be carefully planned, Computer-aided production monitoring of the complete weaving process helps to keep the looms running at high efficiency levels.

There are several basic weaves. The simplest is called the plain weave, in which pieces of yarn pass over and under each other alternately. In the twill weave, the filling yarns go over and under two or more warp yarns at regular intervals, creating a diagonal pattern. In satin weave, the intersections of warp and filling are varied, resulting in a tightly woven cloth with a smooth appearance. One of the most famous looms for intricate patterns is the Jacquard loom. The pattern for this fabric is programmed on a series of punch cards similar to modern computer cards. The cards, in turn, manipulate the warp yarns to create the desired pattern. Flowered bedspreads, towels, and decorative fabrics such as upholstery are produced in this way.

Knitting.-The knitting process is divided into several distinct segments. Some knitting mills are like weaving mills, in that they manufacture rolls of fabric for shipment to apparel plants to be cut and sewn. Others specialize in particular apparel, such as knitted underwear, sweaters, pantyhose, and socks. The different types of knitting are usually made on different machinery and m different plants.

The basic distinction between knitting and weaving are that the woven yarns are interlaced together and the knitted yarns are looped; a knitted fabric is a series of interconnected loops. The most frequent knitting processes are weft or warp knit production, performed on a flat bed knitting machine or on a circular knitting machine, and single or double knit production.

The knitting process consists of hundreds or thousands of needles in a row or a circle, which pull yarn through the loops. The spacing of the needles determines the gauge of a knitting machine. The whole process makes the impression of being more continuous than the weaving process. The number of knitting positions determines the productivity of the machinery. All yarn preparation processes through winding are required in the knitting process, but neither warping nor slashing are necessary. Yarns come to knitting directly from the winding machine.

Nonwoven Fabric Manufacture.—Some nonwoven fabrics are produced directly from fiber by machines that apply combinations of heat and pressure to fuse the fibers into fabric. Fabrics that are bonded this way have greater porosity, better shape, higher bulk, and nonraveling edges. Other fabrics are "needle punched, " or produced directly from fiber by machines that tangle or mat fiber. Laminated fabrics consist of two fabrics, or fabric and a material like urethane foam bonded together by heat or chemicals.

One very popular nonwoven process is tufting. Tufting is the most widely used process for carpet manufacturing. In this process, a bar carrying a row of closely spaced needles is positioned above a flat backing fabric. Each needle is supplied with a yarn drawn from a separate yarn package, forming one of a number in a creel in the back. The needle bar is lowered so that the needles pass through the backing fabric to a controlled distance, where a corresponding number of loopers are positioned. Defects in the fabrics are easily corrected by a hand tufting machine, without any quality loss. One tufting machine usually requires one operator. The tufting operation is capital-intensive, and there is potential for future automation of the process with concurrent increases in productivity.

Finishing.–Fabric must be bleached, dyed, or printed before it is ready for use. [t may also be sheared, brushed, or scrubbed. Fabric may be treated to repel water or to absorb it. It can be finished to make it rigid or soft. Some textiles are coated with plastics, in order to produce the look and feel of leather. Others are finished to look like the fur of wild animals.

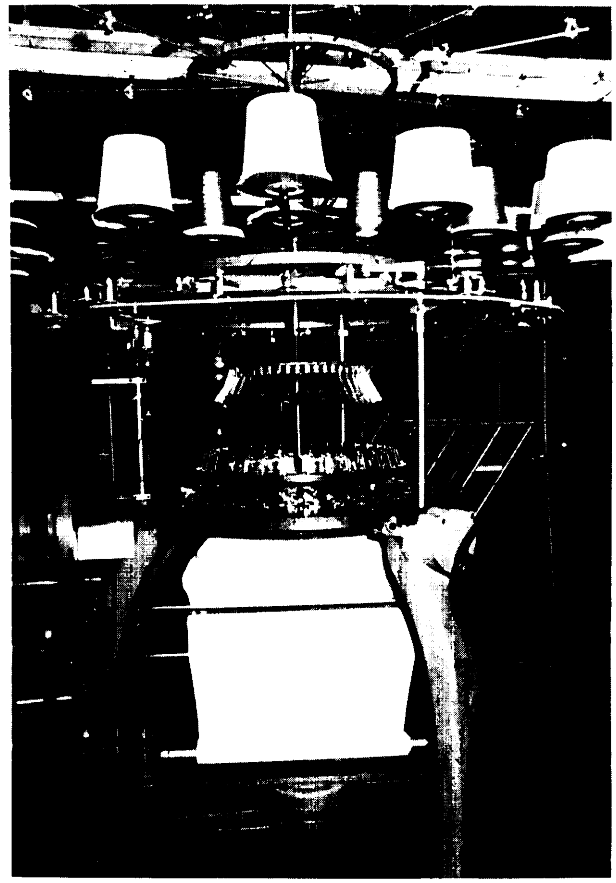


Photo credit" Char/es *Gardner, School of Textiles, North Carolina State* University

A traditional, plain-jersey knitting machine,

Technological Innovations

Innovations are occurring throughout the process of fabric formation. In addition to innovations already being adopted are those pending development and those that need to be developed.

Innovations in Specific Areas of Fabric Formation

Weaving.—Traditionally, weaving has been accomplished on a shuttle loom. A new technology

for weaving, the shuttleless loom, has emerged since the 1950s, and has virtually revolutionized the weaving process.[26] These looms operate at faster speeds and require fewer auxiliary operations than shuttle looms. The four basic types of shuttleless looms are:

1. missile or projectile;
2. rapier—flexible, rigid, and telescopic;
3. air-jet; and
4. water-jet.

There are also multi-phase looms, which may combine weft-wave or warp-wave systems with shuttleless technologies.

Although the majority of the world's weaving industry is still dependent on shuttle looms, there is no doubt that their share of the market is steadily decreasing. Rapier and projectile looms have been the most widely used since the mid-1970s. Water-jet looms were more widely accepted than air-jet, mainly for filament weaving, because of their greater width and speed. Recent advances in air-jet looms, however, give air the edge over water, and air-jet weaving is expected by many experts to be the most widely used shuttleless system of the late 1980s.

Projectile Looms. —The two basic types of projectile looms are the single and multiple projectiles. Single projectile looms have not made a major impact in the industry, due to low rates of filling insertion. The projectile is accelerated and stopped by compressed air. Major manufacturers are Investa and Crompton & Knowles.

Multiple projectile looms are manufactured by Sulzer, although others produce the same loom either by license or by duplicating the Sulzer loom. The gripper or projectile used on the Sulzer loom is capable of inserting the filling in one direction only, and is projected at a speed of approximately 100 feet per second through guides. The grippers are returned to the picking side by means of a conveyor chain, one per 10 inches of chain length.

The Sulzer loom introduced a number of new concepts to loom design. The first is the use of strain energy of a torsion bar to activate the picking. The second is the use of cam-driven lay with a long dwell in the back center, and the use of guides to ensure a straight line path for the projectile. Other new features are tucked-in selvedge, and a different reed design that allows for more air-space between wires. This particular design is thought to be responsible for the reduction of warp breaks on the Sulzer loom.

The Sulzer loom is a highly engineered machine, which has been refined over a 30-year period. The loom is available in tappet, dobby, or jacquard, and in single- or multi-color filling. A new and significant development is the Crompton & Knowles air-propelled projectile, in the form of a tube: a length of filling sufficient for one pick is crammed into the plastic tube prior to the insertion. Picking occurs from both sides, as on conventional looms.

Rapier Looms.—The three basic types of rapier systems are rigid, flexible, and telescopic. In some cases, only one of these three types is used to insert the pick from one side to the other. In other cases, two rapiers are used, and one of the rapiers takes the filling yarn to the center and delivers it to the second rapier, which then takes it to the other side of the fabric. New developments in rapier looms include considerable refinements in weaving a wide range of yarns, offering four-, six-, and eight-color selection mechanisms for filling. Increased width and speed of most rapier looms qualify them to be considered by many as the conventional looms of the future.

One of the most significant developments in rapier looms is the two-phase Sauer-500, in which a rigid rapier is used to insert the filling in two fabrics

[26] This discussion of specific types of shuttleless looms is based largely on M.M. Mohamed, "The Current State of Weaving, " North Carolina State University, Raleigh, NC, 1984.

woven side-by-side on the same loom. This development eliminates the space requirement problems of the single-rigid rapier loom. The rapier is driven in the middle of the loom, and enters one warp shed as it leaves the other shed. All functions of the loom lag by a phase angle of 180 degrees on one side, as compared to the other side. A rate of filling insertion of up to 1,100 meters per minute is possible.

Air-jet Looms. -Even though air-jet loom development can be traced back to the 1920s, the modern era in air-jet weaving has taken place over two stages. The first stage was the development of the Maxbo loom. Each loom had its own compressor, and was limited in width to about 100 centimeters because no control was used on the air flow through the shed. Due to this limitation, air-jet weaving did not receive much attention during the early 1960s. The second stage, which started in the late 1960s and early 1970s, is characterized by the development of jet control systems and the use of auxiliary nozzles. These events made it possible to have loom widths up to 330 centimeters and speeds up to 600 parts per minute. Many experts believe that air-jet looms will increase their share of the shuttleless market, especially at the expense of water-jet looms. This is mainly due to the flexibility of air-jet looms in weaving filament and spun yarns.

The three main types of air-jet looms are single nozzle with confuser type guides, multiple nozzles with guides, and multiple nozzles with profile reeds—each of which has advantages and disadvantages. Systems that use guides tend to suffer from a high level of abrasion between the guides and the warp. The use of a reed reduces the level of abrasion, but tends to increase the cost of production due to the high cost of the reed; however, Ruti, the Swiss company, has developed a semi-profile reed, which can be used with plain weave fabric and reduces the cost of a profile reed.

Although modern air-jet looms represent a tremendous advance in weaving, there are still limitations to be overcome. One example is the restriction on multi-color filling. Even though Ruti has developed a system of filling mix that uses two main nozzles oscillating up and down, only one color was used. Also, the use of fancy yarn in the warp or filling direction still presents a major challenge. In addition, fabric weight is limited to light and medium weights of about 400 grams per square meter.

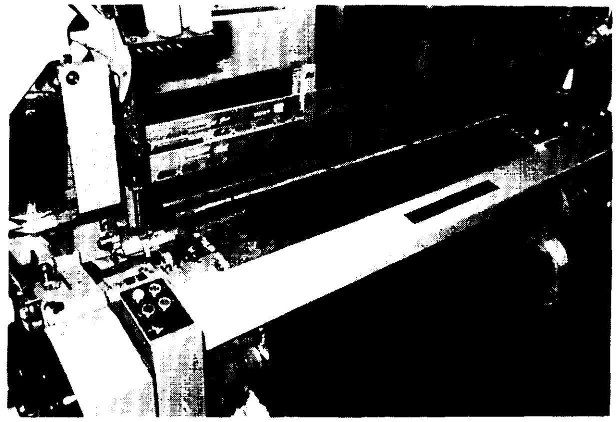


Photo credit Char/es Gardner, School of Textiles North Carolina State University

An air-jet loom: Electronic controls help make this technology faster and more efficient than shuttle looms.

Water-jet Looms.—With water-jet looms, a water-jet takes the yarn across the shed. Water-jet looms achieved higher speeds at larger widths than early air-jet looms. But water-jet looms have the disadvantage of being limited to filament synthetic yarn. Other disadvantages are that the warp has to be sized with a nonwater-soluble size, and that the fabric has to be dried.

Although experts predict reduced market growth for water-jet looms, there are two recent important developments. First, Nissan has developed a “Super Speed” loom that operates at a speed of 700 parts per minute with a 72-inch width. Second, Investa has modernized its OK-6/H2000 loom to use two central nozzles at the middle of the loom, thus enabling the loom to weave double-width and to use two-color filling. Water-jet looms have also been very successful in weaving fiberglass, lining, and taffeta fabrics.

Multi-phase Looms.— instead of the sequential functions of shedding, filling insertion, and beat-up of single-phase looms, a multi-phase loom can perform these three functions simultaneously and for more than one shed. The two types of multi-phase looms are weft-wave and warp-wave.

In the weft-wave system, the warp shed is divided into a large number of sections that operate independently from one other. Filling carriers have a piece of yarn long enough for one pick, and enter the warp from one side. As they progress across the warp, each shed changes for the next carrier. Beat-up of the pick also occurs in segments, after each part of the pick is inserted. The most important feature of this type of loom is a high rate of filling insertion achieved at a reduced noise level. The main drawback is a limitation on yarn range and fabric design.

With the warp-wave system, the sheds are created for the full width of the warp. Filling insertion occurs in more than one shed simultaneously; beat-up is done over the entire pick. The Bentley "Orbit" loom operates on a curve's cylindrical warp path, and claims to reach a rate of filling insertion of 3,600 meters per minute for a two-fabric loom, using rigid rapiers to insert 18 picks simultaneously in each of the two sides at the rate of 100 times per minute. The "Orbit," however, suffers from limitations of fabric width and design construction.

An ongoing development that will combine the use of air-jet insertion and flat warp-wave shedding is the McGinley loom, which uses conventional shedding like cam dobby or jacquard. Using guides that will become a tube for the air and filling insertion, the amount of air needed per pick will be considerably reduced.

Shuttleless looms have the following advantages over traditional fly shuttle looms:

- productivity of some shuttleless looms is as much as three times that of conventional shuttle looms;
- cloth can have greater width;
- cloth flaws are reduced, thus improving fabric quality and marketing;
- noise levels in weaving rooms are reduced;
- temperature and humidity control, demanded by the sensitivity of the machinery, improve both the cloth quality and the work environment; and
- traveling cleaners on the equipment take care of more dust problems at the source than traditional cleaners.

Dyeing **and Finishing.**—There is a general view that the number of discrete processes in dyeing and finishing needs to be substantially reduced, and that as many as possible should be combined. The goal would be to make dyeing and finishing a truly continuous process, rather than a series of batch processes each with its own control and materials handling problems. What this suggests is the development of sophisticated monitoring and control systems for dyeing and finishing, the more important of which seem to be the ability to monitor and control both the color of wet fabric and the moisture content. The aim is to be able to predict accurately the color of the final dry fabric by measuring its characteristics at the moment it is being dyed.

Continuous dye ranges now have considerable automation, but they are hampered by an inability to run very small lots efficiently. Systems need to be developed that will allow rapid changeover from lot to lot on a continuous range system, with a minimum fabric band between the changes. In addition to suitable monitoring and control functions, ways to rapidly alter dye baths in order to change color must be developed quickly. The aim is to produce systems with very rapid response times. This will require precision instrumentation for adding chemicals and controlling the parameters of the process.

It is also important to have absolutely uniform desizing and bleaching. In this area, there may also be applications for computer-based monitoring feedback and control systems. There are general needs for reducing the energy cost in dyeing by reducing either the setting or the drying requirements. For some products, it would be useful to have dyeing be the last of all finishing steps, in order to improve order and warehouse versatility. Finally, the development of continuous computerized finishing integrates dyeing and finishing techniques, incorporates computerized instrumentation, reduces unit labor costs, and improves quality.

Innovations in Fabric Formation[27]

Automation is a major trend throughout the textile industry complex; most current applications of robotics are in the area of materials handling. An important concept, related to automated materials handling, is automated identification of the material, which allows for the recognition of quality control problems with respect to their material source. Such automated materials handling is, or eventually will be, built into process technology itself, but ma-

[27]The following discussion is based largely on D.R. Buchanan and G.A. Berkstresser, "Automation in the Textile Industry: Prospects and Impacts," North Carolina State University, Raleigh, NC, cited in "Technologies for the Textile and Apparel Manufacture in the U.S. ," contract report prepared for the Office of Technology Assessment, February 1985, pp. 295-309,

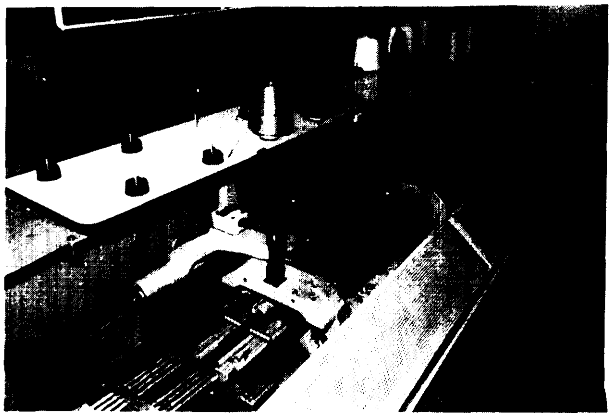


Photo credit: Charles *Gardner, School of Textiles, North Carolna* State University

This modern knitting machinery permits increased flexibility and productivity in fabric formation.

terials handling problems that will require special technologies remain—the newest of which are driverless vehicles and robots. Of all the technological developments emerging in the textile and apparel industry, the increase in automation and monitoring of fabric production processes has had the largest impact on productivity and product quality.

Pending Technologies. -Pending innovations in fabric formation are almost all in the areas of monitoring and control, inspection, and materials handling. Modern weaving and knitting machinery allows the choice of many options, facilitating the decision of whether to emphasize productivity or flexibility. The important trend outside the design of fabric formation machinery is the elimination of menial materials handling jobs. As an example, fabric handling with driverless tractors is well proven, although this is an area in which potential savings—other than those associated with labor—are difficult to identify. In conjunction with automatic inspection and grading, it would also be desirable to devise systems for automatic doffing of cloth and automatic cutting.

Inspection of fabric is thought by many to be a process that might be eliminated if suitable process monitoring and control systems are invented. There is, however, a difference in philosophy, depending on whether a greige mill or a dyeing and finishing plant is involved. In the former case, it is more likely that inspection could be eliminated if the finished fabric is inspected later; there will always be a need for some inspection, but it can be automated. In particular, inspection systems should be capable of viewing the fabric with both plant capabilities and customer demands in mind, changing the latter with respect to the customer and changing the former with respect to the fabric style. Computer-controlled inspection systems should also interface with computer-controlled cutting systems, to optimize the cutting of quality yardage. These issues become more important as the textile industry moves to higher quality and greater output levels, when inspection speeds could limit process speeds.

Monitoring in weave rooms and other fabric formation areas is done generally for the purpose of producing management information. Although this is an important function of such systems, diagnostic monitoring that will locate and diagnose loom malfunctions—preferably before they lead to producing off-quality material—are also needed. Such systems would be part of a larger monitoring system that could deal with the flow of raw material into the fabric formation process, or with the fabric formation itself. The development of truly reliable monitoring and control systems is closely related to the development of automated inspection systems, since the latter depend on the assurance that defects are minimized in the process.

Needed Technologies.—The technological revolution has already occurred in fabric formation, with the development and increasing adoption of shuttleless weaving. Nonetheless, at least six technological developments are expected to be the focus for future advances. These developments center around increasing the amount of automation in the process, reducing the number of manufacturing steps, and gaining fuller control over production processes than over changing machinery technologies. The six developments are:

1. monitoring and controlling of slashing,
2. weaving without size,
3. new slashing techniques,
4. fewer steps,
5. built-in cleaning, and
6. microprocessors and CAD/CAM[28] for loom changes.

The Impact of Robotics.–Robot v. *Hard Automation.* —While hard automation dominated techno-

[28]Computer-aided design/computer-aided manufacture

logical developments in the textile and apparel industry of the past, some predict that robots may be the trend of the future. To date, new technological developments in the industry have emerged primarily from custom-engineered, automated manufacturing machinery, built to accomplish a specific set of tasks and incapable of doing other tasks without disassembly and rebuilding. This process defines "hard automation. " Robots, however, whose applications have already revolutionized the automotive industry as well as some simple textile tasks, are defined as:

> . . . reprogrammable multi-functional manipulators] designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.[29]

Clearly, a robot is something quite different from a piece of machinery classified as hard automation. The extent of future automation through the application of robots is still an issue of hot debate within the textile and apparel industry.

Hard automation is used for such technologies as automatic knot tying devices, which do what humans had done previously with greater consistency. Modern techniques of yarn splicing, however, represent a process that humans cannot duplicate. Other developments include faulty end detection using computer-driven detection systems, and production monitoring using computer-controlled systems. Also, among the more inventive materials transfer schemes are ring-spinning yarn packages brought to a winding frame.

Currently available robots can have most, if not all, of the following characteristics:

- spatial flexibility, with up to 6 degrees of freedom,
- teaching and playback capability,
- memory of any reasonable size,
- program selection by external events,
- position repeatability to 0.3 mm,
- weight handling capability to 150 kg,
- point-to-point or continuous path control,
- synchronization with object movement,
- interface ability with external computers, and
- high reliability—typically 400 to 500 hours between failures.

Pending Developments in Robotics.—Textile uses for robots will probably not become revolutionary but will remain evolutionary, until most of the following seven items have been developed to the point that they are available at a reasonable cost:

1. vision, for recognition, parts orientation, and flaw detection;
2. tactile sensing, for recognition, orientation, and physical interaction;
3. real-time, computer-based interpretation of visual and tactile data;
4. general-purpose versatile effecters, or "hands";
5. mobility, or the ability to move from one work station to another;
6. self-diagnostic error tracing; and
7. inherent safety.

Entire robot systems, in which integrated and interrelated technologies operate with a minimum of human supervision and intervention, are likely possibilities for the future. Hard automation will likely be part of such an automated factory, unless some way is found to substitute some of the successfully automated textile machines with robots. Most experts predict that hard automation will be accompanied by robots, particularly in materials transfer assembly and special operations applications, At the front end of such a factory, it could be expected that computer-aided design, as well as transfer of instructions and information directly to the manufacturing machines will be a featured. In addition, information from a sophisticated computer-based system will be sent to management for use in decisionmaking.

Three areas for likely use of future robot systems in the textile industry are materials transfer, inspection, and process control. More sophisticated systems of materials transfer are likely to emerge, especially with respect to mobility; a number of spinning frames could be served by one system, for example, and the output directed to a number of places. These materials transfer systems will also have much more sophisticated sensing systems, and may even monitor quality as they perform transfer tasks. More sophisticated versions of the driverless vehicles now available are also likely to emerge. These may have even more sophisticated computer control, and would probably not depend on floor tracks for their guidance system. If the latter were developed, this would represent peak flexibility for these devices.

Effective inspection will take place automatically at many more positions in the textile processes of

[29] The Robot institute of America

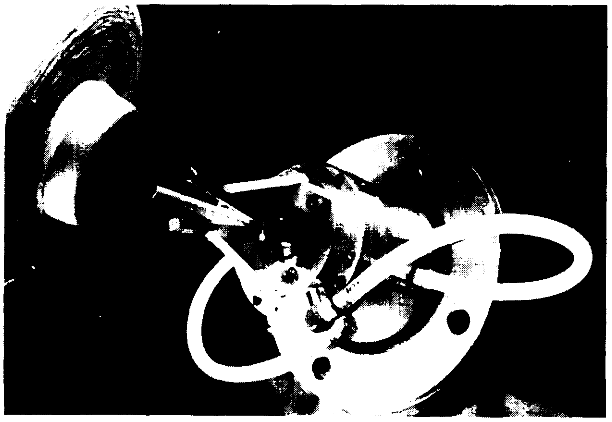


Photo credits: Charles Gardner, School of Text//es, North Carolina State University

This robotic device (above) inspects yarn to determine whether yarn quality is sufficient for knitting. Such technologies are replacing the hand inspection process (below), and allow for greater flexibility, more accuracy, and faster speed during inspection.

the future than in those of today. Inspections will utilize rapid response, vision, and/or tactile systems in some cases; in other cases, transducers will measure physical properties. In addition, the overall inspection system will be programmable, to allow decisionmaking based on both plant and customer specifications; these may be changed nearly instantaneously as the product being manufactured changes. Finally, such a system has to provide a complete management information package on demand, and this probably will be a built-in part of future innovations.

Real-time, efficient sensing systems will be needed for process control, and these systems should be able to operate at nearly every phase of the textile product manufacturing process. In addition, they will have the ability to maintain complete records of a product's history, and of its complete component and process identification. This will be extremely useful when production difficulties occur.

Robots represent a logical extension of the hard automation developments in textile technology, which started with the Industrial Revolution. The importance of future developments will depend on the degree to which robots and hard automation are combined with computer control of design and information systems, in order to form flexible automated factory systems capable of producing high-quality, low-cost products that can be sold profitably.

Impact of Automation on productivity.–The cumulative effect of a continuing flood of inventions since the Industrial Revolution, mostly in the hard automation class, has been dramatic improvement throughout the textile industry. In each 70-year period since 1760, productivity in yarn and fabric formation increased tenfold. The introduction of robots into the industry should assure a continuation of this historical trend of rising productivity.

The improvement of quality in processes that use sophisticated automation, and particularly in robot applications, is largely the result of enhanced repeatability and reliability. Depending on the job, it is possible not only to work more efficiently, but to effect savings in parts or supplies because of the greater efficiency of robotic applications. This can be facilitated by interfacing with feedback and control loops for rapid response to external events. Finally, there is a view that human intervention in the manufacturing process should be restricted to the greatest extent possible, in that many human functions, such as handling, are actually detrimental to quality.

The enhancement of flexibility occurs particularly with robotic applications, due to the possibility of reprogramming in a simpler fashion when circumstances dictate. Since there is an identified trend in the textile industry towards increased levels of manufacturing adaptability, the flexibility built-in to automation can be of value to a firm that is close to the marketing and fashion end of the business. While humans represent the ultimate in flexibility and adaptability, it is quite conceivable that robots may be able to replace some human functions in manufacturing processes that require high levels of flexibility.

Impacts of Automation on General Management.—Over the centuries of development in the textile industry, management has had to adapt to change, but the rates of change of the past were more gradual than those of today. Frequently, "trial and error" methods of adaptation worked. But the predicted rate of change that will face the industry over the next several decades may be so rapid that management will not have the luxury of a long time period in which to adapt. Those who wait and try to adapt to future changes, rather than planning for their emergence, may not survive.

For the U.S. textile and apparel industries to enjoy the benefits of robotic systems applications, management must recognize that entirely new approaches to human factors and financial management maybe required. The structure of the industry may have to change in order to survive in a global market economy; indeed, the $55 million spent by Burlington Industries to modernize its Erwin plant is going to look very small in a few years. Even with moves toward higher value-added products, survival is not guaranteed.

Recent research on textile industry structure indicates that large firms, with access to large amounts of capital and large economies of scale, show the highest productivity using the value-added measure. Small firms, with the least access to capital but high flexibility and usually producing high value-added products, have the next highest productivity. Medium-sized firms, which have been a very important segment of the industry, face both limited access to large amounts of capital and limited flexibility, resulting in the lowest productivity. As the industry moves toward a more capital-intensive structure, the dominance of larger firms increase.

Impact of Automation on Human Factors Management.—The impact of automation on human factors management will be pervasive. The following areas are likely to change;

- traditional practices of recruiting large numbers of low-skilled workers, and relying primarily on on-the-job training, may need revision;
- fewer workers will be needed, but those who are needed may have to possess higher skill levels;
- textile companies may not be able to afford traditionally high annual labor turnover rates;
- management may have to revise the standard layoff-recall practices that have been used to adjust output for demand; and
- new technologies may bring massive changes in the man/machine interface, implying changes in managerial skills as well.

Training supervisors in textiles and apparel has always centered on developing the ability to manage substantial numbers of low-skilled workers, while the factories of the future are likely to demand supervisors who manage fewer people performing more highly skilled functions. If the current labor or supervisory force cannot make the transition to the new system, the industry may need substantial restaffing. The costs and time required to train more highly skilled workers and supervisors would then increase, giving larger firms an even greater advantage over more moderately sized companies.

Other industrial nations have already made plans to address these human factors aspects. The European Community has provided $1 billion in funding for retraining of textile and apparel workers, and for wage subsidies during training. Sweden has its own $27 million fund for retraining and relocation for displaced workers. The United Kingdom has a $110 million fund that includes money for retraining, and Spain provides funds for early retirement of excess employees.

Industrial Structure[30]

The Weaving Industry

The U.S. weaving industry consists of hundreds of companies, both large and small, which compete in the cotton and raw fabric market. The fabrics produced by weaving firms are intermediary products, which are then sold for further fabrication.

The industry is defined by:

- nearly identical manufacturing technology and machinery,
- easy substitutability of products,
- similar channels of distribution, and
- high expenditures for new plant and equipment.

Companies in the weaving industry are horizontally and vertically integrated in different degrees. Production of fabrics is done both at large- and small-scale locations, resulting in different degrees of flexibility. The ability to move between large-scale production and flexibility is the key to success in the weaving industry. Fabric production for some producers is only a small percentage of their total production, whereas it is the only product for others.

The industry has frequently been revived by the introduction of new weaving technology. The newest technologies for shuttleless looms, for example, have significantly increased productivity. Clear signs for the rejuvenation of weaving have been the more than doubling of fabric exports, and substantial increases in output per employee.

Capital expenditures are concentrated mostly in large-scale production facilities. The concentration of the four largest companies, which is currently around 40 percent, is likely to increase; these companies benefit from enormous economies of scale. Nonetheless, the total number of companies has also risen slightly in recent years, primarily due to a combination of low entry barriers and the potential for higher earnings.

Technology is largely supplied by several foreign machinery producers. The development of machinery is a high-technology matter in the hands of a few companies, which compete in an almost oligopolistic market. The frequent updating of technologies that substantially improve productivity requires high expenditures.

The profitability of the weaving industry is largely determined by:

- high degree of rivalry among corporations,
- increasing degree of substitutability, of the different textile fabric types,
- low bargaining power of these corporations against their suppliers,
- high price competition among the producers, and
- low barriers of entry and exit.

The rivalry among fabric producers is high. There are about 200 companies in the cotton weaving industry, and about 250 companies in the manmade fiber weaving industry. All fight for market shares in a low growth market, where expanding market share for one firm means decreasing shares for the others. Fabric producers face the additional problem of being cost-efficient in large-scale plants, but of losing production flexibility if they grow too large. With more than 1,000 different fabrics in demand, flexibility within a single firm is difficult to achieve. Fabrics, both woven and nonwoven, are highly substitutable.

Competition in the weaving industry is a question of price. The more vertically integrated firms have a slight advantage, in that they can add the margin at the textile end-product stage. Cost advantages can also be achieved by higher productivity through improved use of technology.

The suppliers of the fiber industries have the potential to enter the weaving industry with relative ease. In addition, larger weaving firms frequently integrate backwards, since entry barriers are merely a function of the high capital requirements for machinery. The skills required for the operation of a weaving plant are not too demanding.

The Circular and Warp Knit Industries

The circular and warp knit industries are essentially fabric forming industries. While they have similar technologies, they generally compete in independent markets—the former in the fabric market for apparel goods, and the latter in the home furnishings market. Warp knit is also used in some underwear. Industry competition resembles that of the weaving industry.

[30] This discussion is based largely on "Technologies for the Textile and Apparel Manufacture in the U S ," op. cit., pp. 146-173,

The circular knit sector currently benefits from productive machinery with computer control and high future prospects of more automation. The warp knit sector, on the other hand, uses complex technology that does not change rapidly. Eastern European countries are the leading producers of this machinery.

The circular knit industry is currently consolidating. In recent years, the number of companies has declined from over 600 to under 500. The number of employees has also declined. In contrast, the warp knit industry is fragmenting, with an increasing number of firms. Improvements in this industry are focused on production, not marketing.

Profitability in both sectors is depressed, mainly because of import competition. The U.S. industry has no productive advantages. Labor costs, even though the industry is capital-intensive, are the crucial factor in competition. Many experts believe that prospects for the industries are dim. Technological advances do not tend to improve financial performance, and imports significantly threaten existing markets.

The Tufting Industry

The tufting industry produces carpets, a highly standardized product guided by standardized technologies. The U.S. industry consists of several hundred large-scale corporations. The industry is defined by a unique manufacturing technology, well-defined markets, and high capital intensity. Tufting technology has reduced the production costs of carpets significantly, and has created entirely new markets in home furnishings. Most tufting companies are independent from textile companies; however, many of the large integrated textile companies have tufting operations as well.

The industry is not highly concentrated, but is growing rapidly. Fiber producers, who play a critical role already, will probably become even more important as industry growth slows. Improvements are needed in both marketing and production, since tufting is largely an export industry; quality and cost advantages over foreign competitors can be increased by extensive R&D from fiber producers.

The profitability of the tufting industry is largely determined by:

- the increasing degree of rivalry among the corporations,
- the innovative capacity of fiber companies,
- the relatively high bargaining power of these corporations against their suppliers, and
- high barriers of entry.

One can, nonetheless, expect substantial numbers of entries into the industry. Entry barriers are becoming lower, while exit barriers remain low.

The tufting industry's supplier firms enjoy a particularly large potential to enter this sector. Industry suppliers consist of large fiber producers that develop special fibers for carpet producers, These fiber suppliers compete heavily on a price basis. Still, the relative bargaining power of the tufting industry with its suppliers is high, and its companies are largely in control of the pricing process.

Rivalry among tufting companies is moderate but increasing. There are 300 to 400 similar sized companies competing. High growth rates have enabled these companies to compete comfortably, without problems of overcapacity. High standardization of both the production process and the product have made it difficult to be distinctive. A substantial experience curve exists, promoting relatively large scales of production. Competition is increasingly forcing a cost emphasis in the struggle for market share.

Technology for tufting is largely supplied by a few machinery producers. The technology is relatively simple, highly standardized, and does not require substantial reinvestment. The units of production are relatively small, and require about one normal-sized room.

Tufting is an emerging industry in a transitional phase, with the corresponding structure of high exports, increasing competition, and a decreasing experience advantage. Prospects for the tufting industry are good, The industry is fragmenting, due to negative returns to scale. As market segments become more differentiated, fiber producers are likely to play an even more essential role in new developments.

Other Nonwoven industries

The U.S. nonwoven industry consists of a rapidly growing number of small-scale firms, which compete in a wide variety of different markets with hundreds of different products. Some of these small firms are owned by large corporations. The industry is characterized by:

- diversity of manufacturing processes,
- easy substitutability of certain products,
- diversity of markets, and
- high expenditures for R&D.

Companies are horizontally and vertically integrated to differing degrees. The nonwoven sector is a small percentage of total production for some producers; for others, it is their entire production. Because of nonwoven fabrication processes, it is sometimes difficult to include this sector within the traditional textile industry complex. However, the industry also exemplifies the tremendous possibilities of a future textile industry. Experts suggest that the textile industry would be well advised not to miss these opportunities, a large share of which may be captured by industries like paper and chemicals.

Profitability is largely determined by several factors, including:

- the high degree of rivalry among competitive products,
- high degree of substitutability of different nonwoven structures,
- relatively high bargaining power of these corporations against their suppliers,
- wide variety of applications for the products, and
- variety of different markets.

Also, high entry barriers contrast with low exit barriers. The most important factor in profitability, however, is that the nonwoven industries are a relatively young market sector—numerous new applications are on the horizon.

Technology for the nonwoven industry is developed by some U.S. machinery manufacturers, as well as producers. The kind of technology used is an important factor in future productivity increases in the industry; others parallel the chemical industry. Some technologies are close to those in the paper industry. One can expect that new processes will boost this industry even further. Standardization within the industry is low with respect to the technologies used, as many new products are related to the development of new machinery and manufacturing technologies.

Suppliers of the nonwoven industries are entering the industry in great numbers. One can expect that this development will afford large multinational corporations—many of which are chemical companies—an opportunity to enter the traditional textile industry. Capital expenditures for technology and R&D are high. But once the standardization of the production technology starts, already the case for certain products, entry barriers will be low, due to production machinery that is inexpensive, small, and productive. The reverse situation, backward integration, is less likely. Nonwoven producers do not have the necessary resources to integrate backwards.

The suppliers' bargaining power is strong for the nonwoven industries. One can expect their importance to increase. The buyers' bargaining power, on the other hand, is low. Most nonwoven products are quite different from one another. Competition is low, so prices can be kept high. The diversity of customers makes it easy for producers to find highly profitable market niches. Furthermore, demanded quantities are large. One example is geotextiles, used in landscaping.

Nonwoven products are highly substitutable. Nonwovens compete with both textile products and products from the paper industries. It is likely that these products will experience cost reduction and quality improvement as a result.

END USES OF TEXTILES

Textile mill products have three major end uses–apparel, home furnishings, and industrial and specialty products. Historically, apparel has dominated consumption. But this is no longer the case. While there are cyclical variations, the other two uses have been growing in importance; apparel's share of fiber consumption remained at approximately 37 percent between 1979 and 1985, whereas the share of home furnishings grew from 31 to 38 percent. Industrial textile products still consume over 20 percent of fiber production.[31]

[31] *Textile Organon*, vol 57, No. 9, September 1986, p. 204

Industrial Structure

Traditional Apparel

The traditional apparel industries, dominated by the clothing industries, account for nearly half of all textile and apparel sales. In 1985, U.S. consumers spent $133 billion on apparel, or nearly 5 percent of total disposable personal income.[32] Production includes the manufacture of men's, boys', women's, girls', children's, and infants' apparel and apparel accessories, excluding footwear. Apparel and apparel accessories are chiefly made by cutting and sewing woven and knit textile fabrics, or by knitting from yarn. Some items are made by cutting, sewing, cementing, or fusing such materials as rubberized fabrics, plastics, and leather.

Unlike much of the rest of the industry, where significant numbers of small- and medium-size businesses are giving way to vertical integration, apparel remains an industry segment dominated by small manufacturers, jobbers, and contractors. Manufacturers perform the entire range of operations of garment making. Jobbers are responsible for their own designs, acquire the necessary fabric and related materials, and arrange for sale; however, they contract out most production operations, with the exception of cutting. Contractors receive already-cut garment part-bundles from jobbers, and process them into finished garments.

The apparel industry is characterized by:

- many small firms,
- ease of entry,
- threat of failure, and
- individual firms acting as price-takers, with respect to supplying firms and retail channels of distribution.

The industry comes close to textbook conditions for "perfect competition," but, ironically, what keeps shops so small is in part the specialization that each has in a particular narrow product line.

Manufacturers can readily expand and contract output through the use of jobbers and contractors, which reduces reliance on heavy capital investment for expansion or the cost of unused capacity for contraction. Indeed, jobbing and contracting are growing, relative to manufacturing (see table 5). In women's outerwear, for example, while there were 35 percent fewer manufacturers between 1977 to 1982, the number of contractors and jobbers increased by 26 and 52 percent, respectively. Apparel contractors contribute approximately $3 billion of the value added to apparel products each year.[33]

Labor-intensive operations still predominate in the industry, and wage costs have become one of the critical factors in competition. Apparel is one of the largest employers of women and minorities. People from small towns with few alternatives, the undereducated, and immigrants are widely employed in the industry, providing a low wage, exploitable labor force. In fact, this system–a mechanism for shifting production from one area to another, in quest of labor cost advantage—is a source of employment for the "hard-to-employ," especially for undocumented immigrants.

According to a study by the International Ladies' Garment Workers' Union (ILGWU), the current expansion of the contracting system means that:

> . . . sub-minimum wages, overtime and child labor violations, and illegal homework are once again commonplace in the apparel industry .34

In fact, there is evidence of the growth of a number of "underground" apparel operations which, according to some calculations, comprise up to 35 percent of garment production in unregulated shops and illegal operations.[35]

As of 1982, there were 16,655 companies operating 18,233 establishments in apparel manufactur-
this excludes knitwear, which is categorized as part of textile mill products by standard industrial classification (SIC), as well as part of such other assorted manufacturing categories as rubber and plastic clothing, surgical corsets, and feathers (see table 6 for branch categories of the apparel sector). Including these other manufacturers brings the number of companies to just over 19,000, and the num-

[32] *Textile Highlights*, op. cit., p. 20.

[33] George Wine, American Textile Manufacturers Institute, personal communication.

[34] International Ladies' Garment Workers' Union, Research Department, "The US. Apparel Industry, 1960-1985, With Special Emphasis on Women's and Children's Apparel," Oct. 18, 1985, p. 10.

[35] Letter t. OTA of Apr. *20, 1986,* from Dr. M. Patricia Fernandez-Kelley, Department of Geography and Environmental Engineering, The Johns Hopkins University, p. 3.

[36] U.S. Department of commerce, Bureau of the Census, *1982 Census of Manufacturers.*

Table 5.—Number of Establishments and Production Workers, by Type of Establishment, Women's Outerwear industries, 1963-82

	Total	Manufacturers	Jobbers	Contractors
Industry: women and misses blouses (SIC 2331):				
All establishments				
1963	1,175	171	157	692
1967	990	285	137	568
1972	971	242	163	566
1977	1,422	424	166	832
1982	1,955	296	369	1.288
Production workers (000s)				
1963	521	91	24	381
1967	501	132	2,8	345
1972	548	141	2.9	378
1977	742	156	3.6	55.0
1982	794	138	7.0	58.6
Production workers per establishment				
1963	443	532	15.3	551
1967	51 0	463	204	607
1972	564	58.3	178	668
1977	522	368	21,7	661
1982	406	466	19.0	455
Industry: women and misses dresses (SIC 2335):				
All establishments				
1963	4,752	970	681	2,434
1967	5,225	1,870	713	2,642
1972	5,567	2,364	712	2,491
1977	6,112	3,444	449	2,219
1982	5,627	2,105	644	2,877
Production workers (000s):				
1963	1771	39.5	9.3	113.9
1967	183.7	54.9	12.1	116.7
1972	187.0	60.5	12.4	114.2
1977	1468	51. 7	8.2	86.9
1982	120.0	27.9	8.1	83.8
Production workers per establishment,				
1963	373	40,7	137	468
1967	352	29.4	170	442
1972	336	256	174	458
1977	240	150	183	392
1982	21 3	133	126	29.1
Industry: women's and misses suits and coats (SIC 2337):				
All establishments				
1963.	2,516	573	455	1,092
1967.	2,101	712	423	966
1972	1,618	386	340	892
1977	1,677	445	316	915
1982	1!512	306	352	853
Production workers (000s):				
1963	755	201	6.6	423
1967	71 6	23,1	8.4	401
1972	649	181	55	41 4
1977	728	194	67	46.6
1982. .	632	132	8.9	41 1
Production workers per establishment:				
1963	30.0	351	145	38.7
1967	341	32.4	199	41.5
1972	401	46.9	162	46.4
1977	434	436	21 2	509
1982	41 8	43,1	253	482
Industry: women and misses outerwear (not elsewhere classified) (SIC 2339):				
All establishments				
1963	1,297	704	153	440
1967	1,100	470	169	461
1972	1,373	476	197	700
1977	1.802	831	189	782
1982	1,746	450	341	955
Production workers (000s).				
1963	51 4	250	3.6	228
1967. .	51 7	225	41	251
1972	71,5	253	39	423
1977	88.3	324	6.5	493
1982	93,5	29.1	87	557
Production workers per establishment				
1963	396	355	235	51 8
1967	470	479	24.3	544
1972	521	532	198	604
1977	49.0	390	34.4	630
1982	536	647	255	583

SOURCE U S Department of Commerce, Bureau of the Census, *Census of Manufacturers, 1982*

ber of establishments to nearly 21,000 (see table 7). The average number of establishments per company is therefore approximately 1.1 for apparel. It is important to note that the number of companies and establishments has decreased since 1982; however, most estimates suggest that little change has occurred in the ratio between the two.

The average manufacturing shop size is quite small. As of 1982, in nearly all branches of women's apparel, the typical size of an apparel shop was less than 75 employees—basically unchanged from the 1950s. In women's dresses, the average shop size is only 21. This decentralization means that whereas industries such as drugs, petroleum refining, tires, steel, or motor vehicles account for 90 to 100 percent of domestic production through the operations of their 50 largest firms, in women's apparel—which accounts for about 60 percent of total apparel sales—the 50 largest seldom make up more than half of domestic shipments. And, in contrast to other parts of the overall textile industry, government data do not show a trend toward concentration in apparel.

Domestic apparel production has grown only moderately in recent years. Using 1977 as a base year, the Apparel Products Index showed a 1984 level of 100.9; industrial production for clothing was only 95.0.[37] And while the volume of apparel in 1967 dol-

[37] Federal Reserve Board Industrial Production, statistical release, Nov 14, 1986

Table 6.—Branches of the Apparel (Knit and Woven) Industry, by Standard Industrial Classification Code Number

SIC code	Branch of industry
2253†	Knit outerwear mills
2254†	Knit underwear mills
2259	Knitting mills, not elsewhere classified
2311	Men's, youths', and boys' suits, coats, and overcoats
2321	Men's, youths', and boys' shirts (except work shirts), collars, and nightwear
2322	Men's, youths', and boys' underwear
2323	Men's, youths', and boys' neckwear
2327	Men's, youths', and boys' separate trousers
2328	Men's, youths', and boys' work clothing
2329	Men's, youths', and boys' clothing, not elsewhere classified
2331•	Women's, misses', and juniors' blouses, waists, and shirts
2335*	Women's, misses', and juniors' dresses
2337*	Women's, misses', and junior's suits, skirts, and coats (except for coats and raincoats)
2339*	Women's, misses', and juniors' outerwear, not elsewhere classified
2341•	Women's, misses', children's, and infants' underwear and nightwear
2342*	Corsets and allied garments
2361*	Girls', children's, and infants' dresses, blouses, waists, and shirts
2363*	Girls', children's, and infants' coats and suits
2369*	Girls', children's, and infants' outerwear, not elsewhere classified
2381†	Dress and work gloves, except knit and ail-leather
2384†	Robes and dressing gowns
2385†	Raincoats and other waterproof outer garments
2386†	Leather and sheep-lined clothing
2387†	Apparel belts
2389†	Apparel and accessories, not elsewhere classified
2395*	Pleating, decorative and novelty stitching, and tucking for the trade
2397†	Schiffli machine embroideries
3069†	Fabricated rubber products, not elsewhere classified (insofar as it includes vulcanized rubber clothing)
3079†	Miscellaneous plastic products (insofar as it includes plastic clothing)
3151†	Leather gloves and mittens
3842†	Orthopedic, prosthetic, and surgical appliances and supplies (insofar as it includes surgical corsets, belts, trusses, and similar articles)
3962*	Feathers, plumes, and artificial flowers (insofar as it includes artificial flowers)

†Branch of Industry specializing in producing articles of apparel for both sexes.
"Branch of industry specializing in producing women's and children's apparel.

SOURCE U.S Executive Off Ice of the President, Office of Management and Budget, *Standard Industrial C/ass/f/cation Manual, 1972*

lars rose, five other important production measures have declined (see table 8):

1. employment of production workers,
2. production hours worked,
3. volume of production in pounds,
4. volume of production in square yards, and
5. physical output in millions of dollars.

But even these discouraging production figures may overstate domestic production. Commerce Department data on domestic apparel production include garments cut in this country and sent abroad for sewing and other processing, under the provisions of Item 807 of the Tariff Schedules of the United States (see box C, ch. 5). These "807" items maybe comingled with goods fully produced in this country and reported to the Bureau of the Census as part of the quantity and value of domestic production.[38]

Intense competition among many small producers is reflected in a slower rise in apparel prices relative to the economy as a whole.[39] Between 1967 and 1984, the wholesale price of all apparel increased 101.1 percent; that of women's, misses', and juniors' apparel rose 79.1 percent; and that of girls', children's, and infants' apparel rose 102.7 percent. For all commodities, wholesale prices increased by 210.3 percent, more than twice as fast as apparel.

Competition in apparel is also demonstrated by comparatively low profit margins.[40] For most of the past three decades, after-tax profits for apparel firms ranged between 1 and 2 percent of total sales. In contrast to a profit ratio of 5.2 percent before taxes and 2.7 percent after taxes for all manufacturing in 1980, the parallel returns in the apparel industry were 3.9 percent before taxes and 2.0 percent after.

Because of the small size of the typical garment firm and the large size of the national apparel market, apparel firms tend to be highly specialized. Most establishments produce a single generic product, or a small number of similar products. This degree of specialization does not exist abroad, where production of a wide range of garments is more common.

[38] International Ladies' Garment Workers' Union, op. cit., p. 7
[39] Ibid., p. 12.
[40] Internal Revenue Service data, cited in Ibid., pp. 12-13.

Table 7.— Number of Establishments Per Company,[a] Apparel (Knit and Woven) Industries, United States, 1982

Branch of industry	Number of companies	Number of establishments	Establishments per company
Women's blouses	1,825	1,955	1,07
Women's dresses	5,489	5,627	1,03
Women's suits, coats, and skirts	1,431	1,512	1,06
Women's outerwear, not elsewhere classified	1,595	1,746	1,09
Women's and children's underwear	477	604	1,27
Corsets and allied garments	134	151	1,13
Children's dresses	490	556	1.13
Children's coats	71	81	1.14
Children's outerwea, not elsewhere classified	279	332	1.19
Robes and dressing gowns	128	135	1,05
Waterproof outergarments[b]	98	112	1,14
Leather and sheep-lined clothing[b]	186	186	1.00
Apparel belts[b]	317	319	1.01
Apparel, not elsewhere classified[b]	362	369	1.02
Schiffli machine embroideries	356	366	1.03
Pleating and stitching	906	912	1,01
Knit outerwear	893	923	1.03
Knit underwear	72	84	1,17
Fabricated rubber products, not elsewhere classified	1,213	1,380	1,14
Artificial flowers	207	215	1,04
Men's and boys' suits and coats	443	528	1,19
Men's dress shirts and nightwear	535	741	1,39
Men's and boys' underwear	61	77	1,26
Men's and boy's neckwear	165	170	1,03
Separate trousers	269	356	1,32
Work clothing	305	544	1.82
Men's and boys' clothing, not elsewhere classified	575	646	1.12
Fabric, dress, and work gloves	78	102	1.31
Leather gloves	80	96	1.20
Total	19,040	20,830	

[a]A company is defined to Include all manufacturing establishments owned by the company, plus all manufacturing establishments of subsidiaries or affiliates over which the company has acknowledged control
[b]This branch of Industry produces items for wear by both sexes

SOURCE US Department of Commerce, Bureau of the Census, *1982 Census of Manufacturers*

Nontraditional Apparel[41]

While most apparel involves the cutting and joining of garments from fabric, knit items use a different technology. The knit sector of the industry is divided into two major categories: hosiery and knit underwear products, and knit outerwear products. Both are facing severe challenges from imports, Product standardization has allowed developing nations to gain quick footholds in this market segment, despite lower labor costs relative to traditional apparel. Prospects for the knitwear sector will depend not only on controlling the level of import penetration, but also on aggressive marketing of identified market niches and perhaps, especially with knit outerwear, by forward integration into retailing.

[41]This section is based largely on "Technologies for the Textile and Apparel Manufacture in the U.S.," op cit., pp 174-189.

The Hosiery and Knit Underwear Industry.– The hosiery and knit underwear industry (SICs 2251, 2252, and 2254) consists of 500 to 600 corporations —some integrated horizontally, others vertically— which compete in two separate homogeneous and undifferentiated markets, the hosiery market and the underwear market.

The hosiery and knit underwear industries are characterized by a common manufacturing technology, the circular knitting process. The products are essentially apparel goods, but with almost no sewing except for knit underwear. Labor costs are considerably lower than those for traditional apparel.

Rivalry among companies is high, due to:

- the large number of firms,
- low growth rates of the markets,
- standardization of the products, and
- diversification of the industry.

Table 8.—Apparel Industry in the United States, Production Measures, 1967-84

Year	(a) Production workers emplt. manhours (thousands)	(b)	(c) Volume in 1967 dollars (millions)	(d) Volume in pounds (millions)	(e) Volume in square yards (millions)	(f) Phyiscal output (millions)	(9) Apparel Products Index (1977=100)
1967	1,268.3	2,299,812	$15,952.2	3,615.4	N.A.	$14,028.3	80.9
1968	1,278.3	2,347,827	17,571,2	3,745.4	N.A.	14,465.1	82.9
1969	1,277.0	2,319,972	17,817.9	3,599.7	N.A.	14,003.6	85.6
1970	1,239.1	2,220,113	18,491.1	3,585.1	N.A.	13,130.4	82.2
1971	1,210.6	2,185,677	17,430.5	3,733.4	9,934	13,231.6	83.2
1972	1,230.9	2,225,876	18,987.1	4,195.0	10,762	14,640.7	88.3
1973	1,257.4	2,267,561	19,475.3	10,244	10,244	14,431.0	89.0
1974	1,188.7	2,100,560	18,608.7	3,746,1	9,910	13,775.7	85.0
1975	1,078.2	1,900,751	18,562.5	3,697.2	9,378	13,516.7	77.6
1976	1,140.0	2,056,519	19,414.0	3,877,8	9,790	13,847.7	91.5
1977	1,130.3	2,014,759	19,579.0	4,158.1	10,497	13,664.0	100.0
1978	1,138.3	2,017,123	20,726.9	4,097.4	10,299	13,915.7	103.1
1979	1,106.1	1,952,828	21,440.5	3,990.4	10,131	13,704.3	98.3
1980	1,079.0	1,916,385	21,440.0	3,939.8	10,060	13,680.3	97.3
1981	1,060.7	1,893,119	21,625.1	3,759.7	9,924	13,747.1	96.1
1982	985.3	1,712,798	20,804.0	3,437.0	9,729	12,652,0	87.3
1983	980.6	1,776,621	21,543.9	4,015.3	10,135	13,306,4	95,3
1984	1,001.5	1,816,785	N.A.	3,772.9	10,086	N.A.	102.8

NA.—Not available

SOURCES Prepared by the International Ladies' Garment Worker's Union, from Cols. (a) &(b) data from U.S Bureau of Labor Statistics (SIC 23-239+2251+2252+2253+2254. Col (c) dollar volume in terms of items produced in the United States as shown in the Annual Apparel Survey, Censusof Manufacturers, and Annual Survey of Manufactures Col (d) U.S Textile Economics Bureau, Inc., *Textile Organon*. Col (e) National Cotton Council of America, *Cotton Counts its Customers Col.* (f) quantities produced in the United States, shown by the Annual Apparel Surveys, Census of Manufacturers and Annual Surveys of Manufactures weighted by average values of different products in 1967 taken from the same sources Col (g) Index of Production for Apparel Products, compiled by the Federal Reserve Board

There are many similarly sized companies which compete in a comparatively low growth market. High standardization of the product prevents competitors from becoming distinctively different from one another. Furthermore, as a result of all firms being on a similar experience curve, the cost structure determines prices.

The key to profitability in the hosiery and knit underwear industry appears to be eliminating the currently high level of standardization among products. It is essential to have excellent marketing programs. Also critical, at least according to some prominent experts, is higher product differentiation and marketing flexibility. While this production-oriented industry has been changing, such developments have tended to be more reactive than proactive.

Some experts see the industry as one in decline. The industry is consolidating into smaller units, and disinvestment is occurring. Technology turnover is low; productivity improvements are unlikely to come from newer technology; and employment is decreasing, as are the number of companies in the industry. Nonetheless, some parts of the industry are showing export strength, suggesting that the low profitability in the industry is due largely to missed marketing and innovation opportunities, and not just to industry structure. Much of the export boost is due to innovations of the fiber companies in new fibers and related products, In summary, the hosiery and knit underwear industry, while currently declining, could be revived with proactive marketing.

Technology for the industry is largely supplied by a few machinery producers, of which only a small percentage are U.S.-owned. Updating of machinery is fairly frequent, making the technology used an important factor in the competition.

The Knitting Outerwear Industry.--The knitting outerwear industry (SIC 2253) consists of several hundred small-scale but growing operations. These companies compete in several different markets, including sweaters, shirts, and general outerwear, While such markets are interrelated, there is much potential for segmentation. The industry is largely part of the apparel industry, but only a small percentage of the production technology involves sewing.

Rivalry among fiber producers is high, due to:

- the large number of firms in the industry,
- the variable size of industry firms,
- low growth rate of the markets,
- high imports,
- high amount of fixed costs,
- standardization of the products produced by U.S. manufacturers, and
- general industry diversification.

Gaining market share in this sector is extremely difficult. The unnecessarily high degree of standardization of apparel products in U.S. markets provides an opportunity for some manufacturers to create strong market niches for knitting outerwear products. But even though manufacturers could substantially differentiate their products, few have done so. In addition, the industry faces extremely high import levels from more flexible firms, which often have higher quality products.

Buyer bargaining power is substantial. Products are competitive, and those of the buyer industry, retailers, are high. Due to the large amount of competition, substitutability among domestic and foreign knitting producers by retailers is relatively easy.

The knitting industry has the potential to integrate forward. The lack of profitability in this sector could be made up for by an appropriate retail chain. Italian outerwear knitters, for example, have successfully opened a retail chain in the United States. This should be possible for U.S. producers as well, since there are no substantial entry and exit barriers in the industry.

Low entry barriers are a function of:

- low economies of scale,
- low product differentiation,
- marginal cost advantages,
- moderate capital requirements, and
- access to the distribution channels.

Low economies of scale provide a good incentive for small and flexible units to enter the industry, if they have access to distribution channels. Disadvantages to firms that lack vertical integration can easily be compensated for through marketing flexibility and better product mix. The industry has a high potential for profits if firms react to consumer demand, if they forward integrate, and if they adopt innovative marketing techniques.

The technology used in this sector is basically mature, and is supplied largely by a few machinery producers—of which only a small percentage are U.S.-owned. Updating of machinery is moderate in the knitting sector, and low in sewing operations. No single competitor has distinctively different technology.

Pending Technology

Cutting Technologies

Most experts agree that the making of markers by computer-controlled systems, as well as the cutting of fabrics under computer control, is a likely development for some aspects of apparel production. And a number of desirable advances in the actual spreading and cutting of fabrics can be envisioned.

Spreading, unlike most other apparel technology, has not changed much in recent years. More important, however, is the question of whether cutting multiple layers of fabric to form bundles will be either replaced or augmented by continuous cutting of fabric, one layer at a time. The current bundle system acts as a buffer between various process steps, creating a reservoir to absorb or augment the flow of material through a system of processes. The bundle system is also directly responsible for the long in-process time that is characteristic of today's apparel processes. Replacing a process that requires a garment to spend anywhere from 2 to 20 days in the manufacturing chain with a process that would allow a garment to appear several hours after cutting makes for an attractive alternative.

The reciprocating knife is thought by many to be the weak link in modern cutting systems; otherwise, current computer-controlled systems are generally adequate. Depending on one's view, what is needed is the ability either to cut more plies more reliably, or to cut single layers quickly with immediate transfer to assembly stations. Reciprocating knives are limited in speed and flexibility, while jet cutters can

Photo credit: Charles Gardner, School of Textiles, North Carolina State University

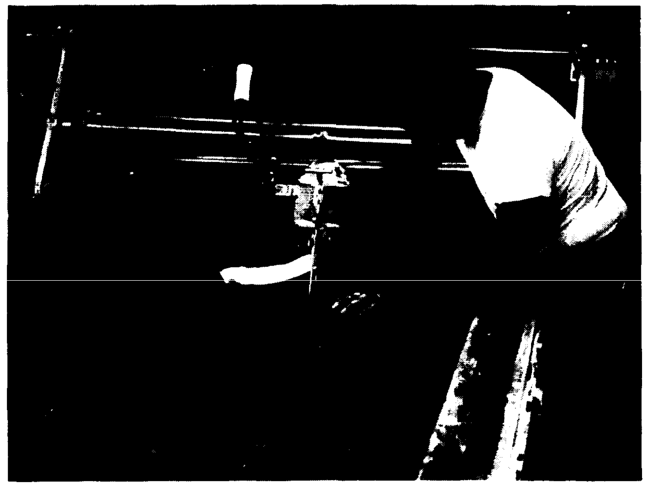


Photo credit: Copyright (©) 1986, 1987 by Bobbin International Inc. All rights reserved

The new computer-controlled apparel laser cutting technologies (left) represent a major advance over hand cutting (right).

suffer severe energy losses if too many layers are presented to them. Laser cutters tend to fuse fabrics that are cut in more than one layer. An ideal cutting system could first be defined by whether multiple plies or individual layers were being cut. In addition, an ideal system could:

- apply to all fabric types,
- have a circular cross-section of minimum diameter,
- operate in conjunction with a computer-controlled guidance system, and
- be able to enter the fabric at the center as well as at the edges.

Materials utilization is of major concern. The amount of waste in cutting can vary from as little as 8 percent for well-placed, computer-generated markers on unpatterned material, to as high as 25 percent for patterned fabrics. Since the fabric cost is roughly one-third to one-half the garment cost, this represents a major loss. Any technological development that could reduce either the waste level or the actual cost of the fabric waste would be of great interest. Areas needing investigation include the packing of patterns with maximum efficiency, the optimization of seams and their associated seam allowances, and the relationship between cutting techniques and waste generation. Other ideas include the building up of garments or garment subassemblies directly from fiber, in order to ensure generation of zero waste.

As cutting technology automates—and as fabric quality continues to improve, making apparel manufacturers increasingly willing to accept fabric without their own quality inspection—some predict that a new degree of vertical integration will emerge, with certain elements of cutting becoming part of textile mill manufacturing.[42]

Joining Technologies

Today, sewing contributes the largest portion of the labor cost to an apparel item, even though as much as 70 to 80 percent of what is ascribed to sewing cost is really materials handling. According to some experts, automation of materials handling, both before and after the sewing machine, poses the greatest potential for successful automation.

It is a widely held view that sewn seams will never be totally replaced. They have both mechanical and aesthetic attributes that are essential in some parts of garments. On the other hand, many have the view that alternatives to sewing can and should be inves-

[42]George Wine, personnel communication.

tigated closely. These alternate technologies would be in the general areas of glueing, fusing, and welding of fabrics. It also seems likely that some of these techniques could be automated more successfully than sewing. There may also be use for these techniques as temporary joints, prior to a final joining by sewing techniques.

Technologies for Apparel Assembly

The apparel sector is characterized by relatively simple technology and a high degree of labor intensity. In the global marketplace of apparel, most experts see a reduction in import penetration and increased automation as the only long-term solutions for the survival of apparel production in industrialized nations. Automation is considered the solution for reducing labor costs, adding production flexibility, and standardizing quality. In addition, there are many new uses for apparel, ranging from space suits to disposable apparel for medical use, and from protective suits for chemical plant employees to lightweight, bullet-proof vests for protecting soldiers and police officers.

Today's basic piece of equipment, the sewing machine, is fundamentally a mechanized tool. It has remained substantially the same throughout the century. This is due primarily to the small and specialized nature of individual establishments, and to the ever-changing styles and fabrics of the fashion market.

Simple technologies with low fixed assets per employee,[43] coupled with management and manufacturing flexibility provided by the contracting system, mean easy entry and exit from the industry and a highly competitive economic environment. Competition is not confined to producers manufacturing the same types of products, but extends to firms that produce substitutes. Firms making dresses, therefore, compete with those manufacturing skirts, blouses, sweaters, suits, slacks, and a variety of other products. Such competition results in a high rate of turnover, with hundreds of apparel firms going out of business each year.

Clearly, the potential for improving productivity in the apparel industry through new technological developments and adaptations is substantial. Where production is sufficiently large in volume, more advanced technologies are being used. This is especially true in fabric spreading and cutting, and in specialized stitching operations.

Most sewing technologies remain homogeneous, and are largely worker-paced rather than automatic. Some new systems for automated sewing are in development, such as the sewing of sleeves for men's suits developed through the tripartite support of government, industry, and organized labor. One such effort, organized as the Textile/Clothing Technology Corp. ($(TC)^2$), spearheads the U.S. effort in automated sewing. $(TC)^2$ has succeeded in automating the production of sleeves for men's suits, significantly reducing the time it takes to manufacture each of 20 million sleeves per year.

During the past decade, research in apparel manufacturing has expanded from the mechanical engineering base to microelectronics applications and a "total systems" concept. Information processing has become highly advanced and lower in cost. This is especially germane to apparel manufacturing, where the number of different bits of information needed to cut, route, and assemble the components of many different styles and sizes of garments reaches enormous proportions. Without relatively inexpensive computers with high memory capacities, it is impractical to automate apparel manufacturing processes.[44]

The development of automated pattern-making and cutting equipment, which replaces operations formerly done by hand, has become technologically feasible since the advent of sufficiently powerful yet relatively inexpensive information processing of microelectronic capabilities. Many apparel firms have already installed computer-assisted pattern making, marking, and cutting systems. Automatic sewing machines are used in some locations, and automatic conveyor systems for handling in-process goods are in evidence in many apparel plants.

The next critical step in apparel automation has been the development of technologies that can identify and pick up a single ply of fabric from a multiply lay, position the piece, and join it to another. Such advances, another result of the efforts of $(TC)^2$,

[43]According to 1981 data from the Census Bureau, the apparel industry (as represented by SIC 23) had average fixed assets per employee of only $4000, in contrast to an average of $31,100 for all manufacturing

[44]Gordon Berkstresser and Kazuo Takeuchi, "Automation: A Fighting Chance?" *Bobbin Magazine*, March 1985, p. 50

Photo credit Copyright (©) 1986, 1987 by Bobbin International Inc.

Graders at H.L. Miller and Son are using the Gerber AM-5 system to remake new patterns out of old patterns stored in the system. What used to take 1 hour when done manually now takes less than 2 minutes.

has been transferred to the Singer Sewing Co., which plans to begin commercial use in late 1987. This innovation, of course, depends on robots that have more than limited decision making and movement flexibility capacities, such as those that exist in current industrial robotics.

Another promising technological development in apparel, currently being worked on at Japan's Research Institute for Polymers & Textiles, is the application of computer graphics to apparel design.[45] Other developments are ready for marketing. Toray of Japan is ready to market a low-cost, microcomputer-controlled, pattern-making system this year. The Nagano Prefectural Research Institute for Information Technology in Japan has developed sophisticated software for microcomputer-controlled evaluation of fabric.

In the early 1980s, the Japanese Government provided $60 million to a special apparel research group. The overall objective of this group has been the development of a system to administer and control the total manufacturing process and to reduce production time by 50 percent, with a pilot plant operating by 1989. Although the project has encountered some difficulty in fulfilling its goal of simultaneously addressing problems faced by both large and small businesses, several of its programs—especially those that target large-scale production—are proceeding vigorously. The group's four specific objectives are:

1. To develop pre-sewing technology, including evaluation of the fabric, material stabilization technology, pattern making and cutting, automatic spreading, and inspection for fabric defects.
2. To automate sewing and assembly of parts, including the development of machines to fold, cut, and bind temporarily; of programmable and automatic sewing machines; and of devices for automatic pressing on forms. Also to be explored is the development of innovative methods of joining garment sections without the use of conventional sewing techniques.
3. To improve materials handling, including creating devices to hold material similar to human fingers and arms, which can transfer garment parts to precise locations; can assemble component parts into segments to be sewn together, such as collars with interlinings; and can transfer parts from one process to the next.
4. To implement a control system with the technology to integrate the production line, especially when types of products are changed, such as the flexible manufacturing system (FMS) concept; to monitor the production line, and repair or replace damaged machine parts automatically; to detect, remove, and replace defects in the goods in process; to establish a method of marking the fabric parts with sewing control information; and to develop devices to read control information during the production process.

A highly automated and flexible apparel manufacturing system will have a profound effect on the distribution system, as will the introduction of sophisticated microelectronic devices in retail stores for customer sizing and selection. This process will require the development of a more sensitive and sophisticated marketing orientation. In other words, the apparel industry must get "closer to the consumer."

If there is to be a technological revolution in apparel, a substantial adjustment by the apparel labor force may be required of both production workers and managers. Unemployment among apparel workers is likely to grow; plans to minimize dislocation could be made now, rather than later. Aside from changes in the numbers and types of production workers, there will be new demands on managers.

[45]Ibid., p. 52

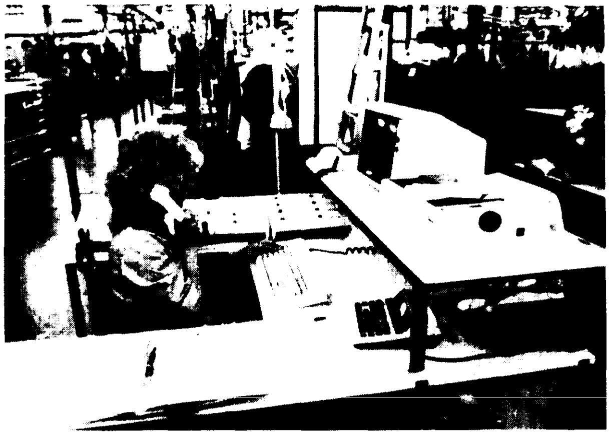


Photo credit: Copyright (©) 1986, 1987 by *Bobbin International Inc.*

This supervisor of a "unit production" system (see ch. 2) monitors a number of workers, parts, and production speeds simultaneously, through the use of advanced computer technologies. The skill level needed by such a manager is clearly different than that needed by the traditional supervisor in a nonautomated apparel facility.

Skills necessary to supervise large numbers of workers using simple machines with repetitive tasks are distinct from skills necessary to supervise automated lines with automated control systems and a few highly trained technicians. Management could also plan for orderly change within its own ranks.

Pending Automation in Apparel.[46]**—The apparel** industry of the industrialized world seems unable, with current technologies, to retain markets. Differences in labor costs are so great that even with the higher cost of long distance shipping, low labor cost countries often have a substantial price advantage. According to many experts, once the surge of imports can be slowed, the best long-term solution for the survival of the apparel industry in industrialized nations is increased automation—which will reduce labor costs, add flexibility, and standardize quality.

Research projects now under way in the United States, Europe, and Japan are demonstrating the technical feasibility of automating apparel production processes. Using computers, development of three-dimensional graphics capability for apparel design has been achieved by the Japanese Research Institution for Polymers and Textiles. The introduction of microprocessor-controlled machine functions can change the sewing operation in fundamental ways, as demonstrated by the "FIGARMA" system developed at the Chalmers University of Technology in Sweden. "FIGARMA," or Fully Integrated Garment Manufacture, is an extension of the concept of flexible manufacturing systems. FIGARMA not only points out critical areas for the development of specific new technologies, but is also a total systems approach that goes beyond technological development and into management areas, such as building computer models for processes needed in planning.

Chalmers, a Swedish company, has a history of apparel technology development. In addition to the FIGARMA approach, this firm is using an Eton overhead rack materials handling unit in its apparel laboratory to conduct research on how computers might be able to position pieces to be sewn together at two sewing stations. Some years ago, Chalmers developed an air-jet, single-ply separator. As in so many cases of this type, however, there was no short-term commercial payback for industry, so the prototype has gathered dust in the laboratory.

(TC)^2, the tripartite endeavor of industry, labor, and the U.S. Government, housed at the Massachusetts Institute of Technology's Charles Stark Draper Laboratory, has made major strides in modernizing the production of men's tailored clothing. Figure 14 provides a model of this technology, which:

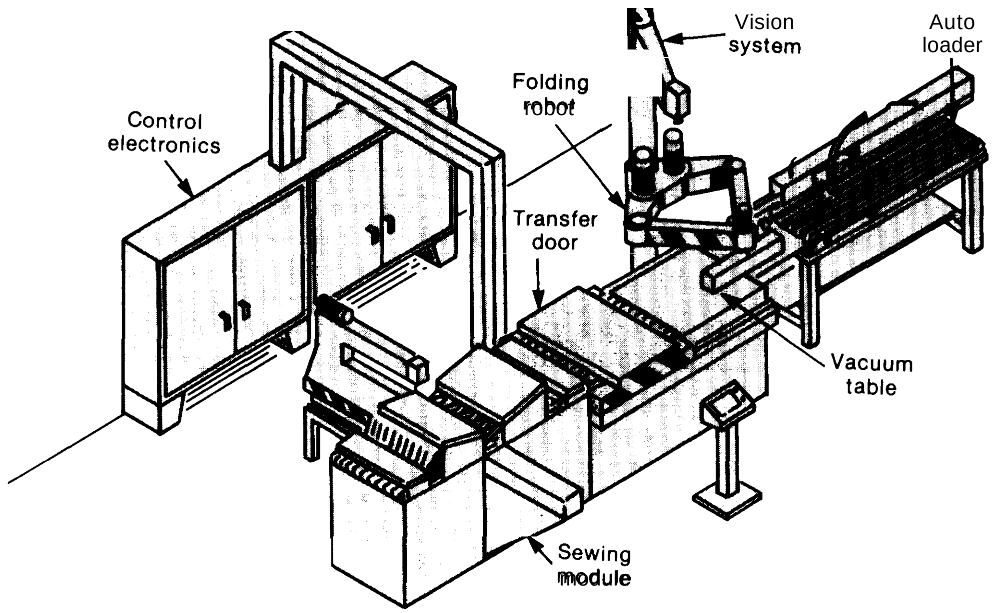
> . . . has developed a computerized production process with robots which will take cut fabric and fully automate the manufacture of subassemblies. The cut fabric will be automatically fed into a machine and, with a computer-aided vision system and robot, will sew, turn, and fold the fabric. The conversion of limp fabric into sewn parts of garments, with the use of computers and robots, represents a major technological breakthrough. Until this development, the use of robots in the production process was essentially limited to rigid materials such as metals.[47]

Having proven success in workable technology for sleeves, coat backs, and trousers, Draper Labora-

[46] This section is based largely on Gordon Berkstresser, Peyton B. Hudson, and Kayuo Takeuchi, "Automated Apparel Manufacturing: A Global Perspective," cited in "Technologies for the Textile and Apparel Manufacture in the U S.," op cit

[47] Statement of Murray H Finley, President of the Amalgamated Clothing and Textile Workers' Union, AFL-CIO, to the Subcommittee on Commerce, Justice, and State, the Judiciary and Related Agencies, Committee on Appropriations, US. House of Representatives, Mar. 3, 1986, p. 4.

Figure 14.—(TC)² Automated Sewing System



SOURCE: *Bobbin Magazine,* September 1986.

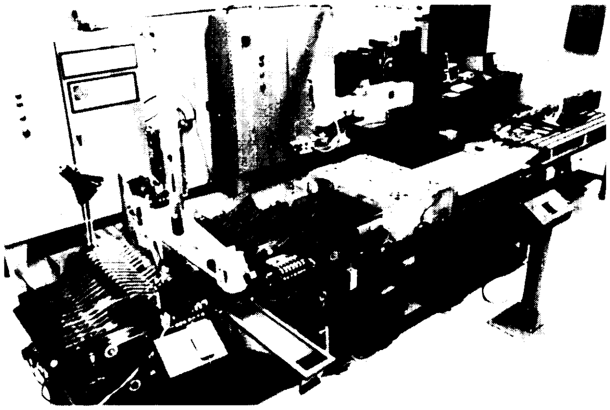
tories are beginning a new activity to apply the technology to knitwear—permitting automatic sewing of knit parts.[48] Production of jacket sleeves was to be the first effort and would be used initially by Palm Beach, Inc. of Cincinnati at their Knoxville, TN, plant, and by the Hartmarx Corp. Future development of a machine to sew trousers may be initially tried by Greif Companies, a division of Genesco, for its Allentown, PA, plant. The plan is to contract with a U.S. machinery manufacturer to commercialize the technology. And the Singer Sewing Co. has placed into production a functional prototype of the (TC)² technology; Singer finds "the presence of a significant market in the near term for application of automated sewing systems."[49] As for the future, Singer's vice president of industrial products has stated that "we are only scratching the surface in terms of utilizing the technology."[50]

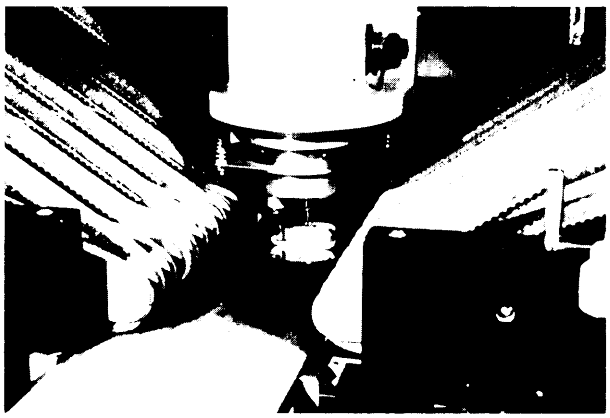
According to Amalgamated Clothing and Textile Workers' Union (ACTWU) President Murray Finley, the payback from technologies being developed today is rapid and substantial. Production time and labor costs can be reduced. The inventory of fabric, in the form of bundles of sewn parts awaiting the next stages of manufacture, is greatly reduced as well.

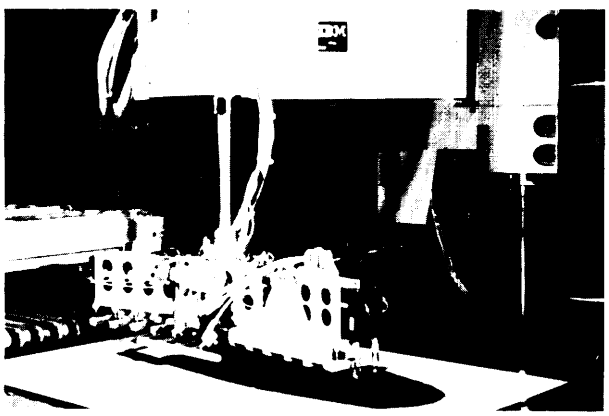
Industry and organized labor are providing approximately $5 million per year for these and similar efforts, and the Federal Government has pledged an additional $3 million, With hundreds of thousands of jobs and tens of millions of production dollars at stake, the amount could be far greater; Japan is spending $80 million to develop a fully automated apparel process for the 21st century, one which dwarfs anything on the drawing boards in the United States. The Japanese plan to develop a system in which a salesman in a clothing store would take a hologram of a customer's body, and digitally controlled machines would then tailor-make an article of clothing.[51] As this goal makes clear, the difference between the United States and Japan lies both in levels of funding and in mandate. While (TC)² is an effort to automate the production of sewing, the Japanese program represents state-led industrial restructuring.

[48] 1 bid., p. 5.
[49] Frank Bray and Vince Vento, "Chapter Two Begins With Singer, " *Bobbin Magazine,* September 1986, p. 170.
[50] 1 bid., p. 174,

[51] Bruce Stokes, "Getting Competitive," */National Journal*, June 7, 1986, p. 1363,





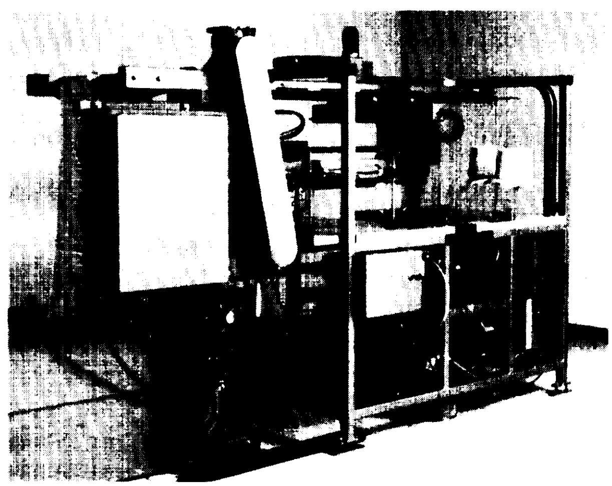


Pictured above is the factory prototype machine of $(TC)^2$, the apparel manufacturing technology developed at MIT's Charles Starke Draper Laboratories. Below are two parts of the $(TC)^2$ manufacturing process: the "interlocking belt system," shown with the interlocked open (middle), which guides the fabric along the surface during production; and the "end effecter" (bottom), which is a high-technology sewing head mounted on a standard robot.

New automated design techniques have also been developed. Designers can electronically "sketch" design, color, and texture onto a computer screen. The design variety is nearly infinite, and multiple possibilities can be reviewed in moments.[52]

Computer-controlled, high speed sewing machines do exist today. However, most experts feel that these machines may be inadequate for the technology of 5 years from now. Some of the areas in which sewing machine architecture and operation could be investigated include: the possibility of three-dimensional sewing rather than flat sewing; independent computer control of both the bobbin and the needle, to allow greater flexibility; and technologies that move the sewing head to the fabric instead of vice versa. This last technique is a major component of the technology developed at the Draper Laboratories by $(TC)^2$. It also is suggested that inspection of the sewing machine could be of considerable advantage, and might possibly be integrated with the sewing process itself.

[52] *Textile Highlights*, op. cit



In addition to apparel production, the Singer Sewing Co. has brought robotics into the manufacture of such end-uses as washcloths (above) and upholstery.

TEXTILE MACHINERY MANUFACTURE

Background

The textile machinery segment of the industry is the smallest of the four. It has approximately 640 plants, employing 18,300 people—12,200 in production—in 1985.[53] While the U.S. textile industry represents the largest single textile machinery market in the world, U.S. machinery manufacturers are losing this market to foreign manufacturers. Whereas U.S. textile machinery manufacturers in 1960 supplied 93 percent of the domestic market, by 1979 the figure had dropped to 55 percent; much of the 1979 sales were in parts, rather than in new, complete machines. By 1982, domestic suppliers held only 48 percent of the market.

Of the $1.6 billion spent by the U.S. textile industry in 1981, only half was being spent within the United States; that portion was largely for parts, materials handling equipment, and less sophisticated machinery. Only about one-quarter of U.S. textile machinery manufacturing firms even make complete machines.[54] The other half of the $1.6 billion, which was spent for high-technology textile systems, went primarily to West Germany, Switzerland, Italy, France, Japan, and Great Britain, The United States, however, continues to be a major producer of dyeing and finishing equipment, and also exports a considerable amount of high- and low-technology textile equipment, equal to 16 percent of total production.

The U.S. textile machinery sector (SIC 3552) is losing ground in other areas as well—not only in the $1.6 billion annual U.S. market, but also in the $7.1 billion world market. World market share for U.S. manufacturers during that same period fell to well under 10 percent.[55] The United States is no longer a leader in the textile machinery market. Rather, it has become a large market for the textile machinery of overseas competitors.

Indeed, spare parts represent a disturbingly large fraction of all sales of U.S. textile machinery firms. Spare parts are only 27 percent of Italy's international sales, 49 percent of West Germany's, and 51 percent of Great Britain's—they are 92 percent of the sales of U.S. producers.[56] As for exports, nearly all U.S. overseas sales of textile machinery are spare parts for previously purchased equipment. This points to past U.S. machinery success, but bodes ill for current and near-future markets—especially for complete machines. U.S. technology is furthest behind the state-of-the-art in projectile and jet shuttleless weaving, open-end spinning, high-speed winding, and knitting equipment.[57]

Most U.S. imports of textile machinery come from Japan and the European Economic Community (EEC), and are concentrated in the fabric and yarn industries. West Germany and Switzerland together account for two-fifths of the world exports in textile machinery, while Czechoslovakia and Japan have emerged as important competitors.

Concentration in the industry is high, and is growing through an increasing number of mergers, acquisitions, and joint ventures. The Swiss-based Sulzer Corp. recently acquired Ruti, its strongest competitor; Sulzer-Ruti has close ties with both Toyoda, the Japanese leader in looms, and British air-jet technology. This enables Sulzer-Ruti to lead technological developments in an oligopolistic manner. Also to be contended with are Hollingsworth-Hergeth, Reiter-Scragg, and Barber-Colman-Warner& Swasey. While such concentration is likely to have a negative impact on competition, the R&D departments of these combined market forces is expected to advance the development of new technology dramatically.

Multinationals are beginning to dominate textile machinery manufacturing. Similar to chemical fiber manufacturers, these global corporations are highly concentrated on national and international levels. In Switzerland, for example, machinery production for the three major processing stages is dominated by Rieter, Saurer, Dubied, and Sulzer-Ruti, four giants in spinning, weaving, and knitting; in Britain,

[53] U.S. Department of Labor, Bureau of Labor Statistics, *Employment and Earnings,* March 1986, p. 46.

[54] *U.S. Industrial Outlook, 1982,* op. cit., p. 205.

[55] U.S. Department of Commerce, "Opportunities and Strategies for U.S. Textile Machinery Manufacturers to Improve Their Competitive Positions in Domestic and Foreign Textile Markets, 1980-1985," September 1980, p. I-33.

[56] Ibid., p. 1-47.

[57] American Textile Machinery Association, *Textile Machinery Statistics,* October 1981, p. 6.

by Platt-Saco-Lowell and Bentley; in the United States, by Platt-Saco-Lowell; in Japan, by Toyoda, Howa, and a division of Nissan, the automobile corporation; in Czechoslovakia, by Investa; in Spain, by Jumberca; in West Germany, by Shubert & Salzer, Sulzer, Zinser, Mayer, Schlafhorst, and Stoll and Terrot; in France, by SACM and ARCT; and in Belgium, by Picanol.[58] The "big eight," ranked by estimated market shares, are Sulzer-Ruti, Rieter, Investa, Platt-Saco-Lowell, Nissan, Toyoda, Schlafhorst, and ARCT. Sulzer-Ruti alone has staked out approximately one-fifth of the global market for shuttleless looms, either directly or through licensing.

There are specific market niches, however, for smaller companies. The Swiss company Maschinenfabrik Jacob Muller AG, a subsidiary of Frick, is a world leader in high-speed narrow fabric looms. Germany's Karl Mayer Textilmaschinenfabrik claims to have 85 percent of the world market for Raschel and tricot knitting machines. While Schlafhorst is a major producer overall, it is also the acknowledged leader in the narrower markets of warping machinery and various automatic and non-automatic winders, Capitalizing on similar market niche opportunities may be one of the most critical strategies for the U.S. industry of the future.

The licensing of technology is a major method for capturing market share. Czech licenses for weaving machines, for example, have been granted to Enshu, Nissan, Toyo Menka, Draper, Crompton, Knowles, and Mayer. And although market positions stem largely from more R&D investment, most U.S. machinery producers lack either the means or the momentum for needed R&D.

Much of the European success is also due to service. The big foreign machinery producers have service facilities in the heart of the U.S. textile industry. Employees speak English, whereas a reciprocal approach seems to be neglected in U.S. export offices operating in non-English speaking nations. Spare parts can be flown in within a reasonable amount of time. Murata of America, a Japanese firm, has headquarters in Charlotte, North Carolina, as do Omintex of Czechoslovakia, and Toyoda and Nissan of Japan. Sulzer of Switzerland, Pignone of Italy, and Hargeth of Germany have offices in Spartansburg, South Carolina. The British firm Platt-Saco-Lowell operates in Greenville, South Carolina. In 1980, Platt-Saco-Lowell boasted an order backlog of 9 months to a year on most of its product lines; that same year, the Sulzer Group had order intake for weaving and knitting equipment of over $430 million—a large increase over the previous year. The joint efforts of Schubert& Salzer Machine Works with Ingolstadt of West Germany also reported record sales in 1980.

Some U.S. companies have experienced growth as well. In early 1980, for example, Automatic Material Handling announced orders of $2.5 million to two U.S. companies for 12 Bale-O-Matics and new hoppers. Another textile manufacturer bought 21 chutes from that firm, and substantial sales were made to French companies. Leesona, Draper, and others—including many air control equipment companies—have also increased sales, both within the United States and abroad.

According to industry analysts at the U.S. Department of Commerce,[59] U.S. manufacturers are not expected to regain the technological advantage they once had in winding and weaving in the near future. On the other hand, they may stay competitive in support equipment and equipment used in opening through ring spinning. By the end of the 1980s, even newer versions of textile equipment are expected to increase productivity, safety, and energy conservation still further, presenting U.S. manufacturers with another difficult but important challenge. The technological and economic results from this development remain to be seen. Creation of the Textile/Clothing Technology Corp. by companies, unions, and government may breathe new life into the textile machinery sector; expansion of such R&D efforts could help significantly.

Industrial Structure

The condition of textile machinery manufacturers in the United States may best be understood from a global perspective. Ernst Nef, publisher of the International Textile Bulletin, writes:

> The American textile machinery manufacturers increasingly lose their position in . . . [both domestic and world] markets. There is no significant loom

[58] F. Clairmonte and J. Cavanagh, *The World in their Web, Dynamics of Textile Multinationals* (London: Zed Press, 1981), p. 226.

[59] *U.S. Industrial Outlook*, 1982, op. cit., p. 206.

manufacturer in production. Spinning machines are produced by Platt-Saco-Lowell. If they have no huge success with the new friction spinning machine, they will lose the whole market. The Japanese machines are better. Leesona is no longer of importance. All the rest are companies which are accustomed to the American market. internationally, they are unimportant.

Draper and C&K used to be the world leading loom builders, whereas Saco, Lowell, and Whitin were the leaders in the spinning machinery sector. Furthermore, other leaders used to be Textile Machine Works, Reading, in knitting and Leesona in texturing and winding. Unifil, Johnson used to be the number one slashing machinery producer.[60]

Nevertheless, U.S. machinery manufacturers have developed new technology to rebuild old equipment, such as new cards and conversion from shuttle to shuttleless looms. Cards can be completely rebuilt, with cylinder speeds increased and setting accuracy improved. With loom conversion costing 15 to 25 percent of the price of a new loom, a company can increase its productivity up to 70 percent by converting conventional shuttle looms to air-jet looms; Leesona and Draper offer loom conversion. However, while the technology for these rebuilding efforts is innovative, it still leaves U.S. machinery manufacturing strengths primarily in the area of parts and servicing of existing machines—not a good prognosis for the future.

The U.S. textile machinery manufacturing industry is well aware of its declining markets in the area of new machine systems. In the introduction to a report from a cooperative grant between the American Textile Machinery Association (ATMA) and the U.S. Department of Commerce, ATMA acknowledges the problem:

. . . the U.S. textile and apparel machinery industries have not kept pace with the high-technology advances being developed and introduced by foreign competitors. The reasons for this lag include the industry's inadequate attention to research and development, its failure to recognize the growing technological strength of foreign companies, and the lack of study and communication needed for the transfer of technology from one U.S industry to another. Often, basic research conducted in the United States is being exploited by foreign competitors, instead of being adapted by U.S. industries. U.S. firms have not encouraged communication among themselves or with inventors; consequently, U.S. patent applications are now in the minority and continue to decrease.[61]

In order to correct for the above deficiencies, ATMA has recognized the need for machinery manufacturers to heighten their awareness of both machinery technology and the state of this technology within the textile industry. Along with the Department of Commerce, ATMA embarked in 1984 on a study to:

- identify needs for high-technology applications to textile and apparel machinery;
- identify potential resources of high-technology research and development, to be applied to textile and apparel machinery; and
- develop an organization to establish long-term approaches, including the development of a high-technology institute for the textile and apparel machinery industries, which would be aimed at the commercialization and the attainment of a greater share of the world market for U.S. manufacturers.[62]

Revitalization of textile machinery manufacturing is considered by most to be crucial to a strong domestic textile industry. Some believe, however, that machinery development in the future could better serve the industry if it were done by the textile manufacturers themselves, rather than by a separate machinery manufacturing sector. That more domestic R&D is needed is not debated; where and by whom, and with how much money and from whom, is very much in question.

[60]The previous two paragraphs are based largely on Ernst Nef, publisher, International Textile Bulletin, Zurich, Switzerland, personal letter, cited in "Technologies for the Textile and Apparel Manufacture in the U.S.," op. cit , p. 341.

[61]American Textile Machinery Association, Development of National Approaches to the Application of High Technology to the Textile and Apparel Machinery Industries, for the U.S. Department of Commerce, Cooperative Grant No. 99-26-07170-10, October 1984, p. 1.

[62]Ibid., p. 2.