Part IV

Design and business

17
Digital printing and mass customization

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17.1 Introduction

Since it was coined in the book *Future Perfect* in 1987 (Davis and Meyer, 1998), 'mass customization' has become an industrial household name and can now be found in numerous articles written on the subjects of innovation, technology management, product development, and supply chain management.

Shifts in consumer behavior have caused many industries, including the soft goods industry, to examine the trend toward mass customization and the technologies that support it. It is a well-known fact that consumers want more personalized products. The companies that will remain competitive in today's marketplace are those that can correctly anticipate consumer wants and incorporate effective business strategies with emerging technologies to respond to those wants.

Digital ink jet printing is an emerging technology that has the potential to satisfy consumer expectations as well as impact company strategy. Ink jet has taken over the office printing market and is now the technology of choice for home printers, even though the print resolution is not quite as good as that of laser printers. Equipment suppliers, textile manufacturers and apparel producers continue to develop applications for the use of ink jet and other digital printing technologies for printing fabrics. The supply chain implications of this technology in the soft goods industry have been apparent for some time and are significant.

How do companies in the sewn products industry position themselves to implement such new concepts? How are the technologies identified? What are the systems and processes that must be implemented, and how are they structured? What role should technology management play in the short term versus long term decisions that are made? Can accurate projections be made regarding the future of a breakthrough technology within an industry? Will digital printing provide a mechanism for the soft goods industry to meet some of the requirements of its customers? The answers to these questions require that industry leaders think about how their organizations are preparing for the future.

This chapter focuses specifically on digital ink jet printing as an enabling technology for mass customization and its potential impact on the soft goods supply chain. In addition, a comparison will be made between a traditional supply chain for woven fabric and a supply chain that will probably exist for digitally printed garments. The intent is to better understand the impact of implementing digital technologies and to explore the relationship to systems that are more capable of adapting to changes in consumer wants and expectations. These concepts have been tested using industry representatives that have a thorough knowledge of advanced technology and are familiar with the latest developments in the soft goods industry.

Several conclusions can be drawn from the analysis. First, business and manufacturing processes can be automated through the use of digital systems. Automation is not restricted to digital technology; however, digital processes can easily be reconfigured and are not as sensitive to changes in production requirements or product attributes.

Section 17.2 consists of a review of the trends in supply chain strategies. The most important take away is that mass customization strategies are infiltrating all types of companies and are rewriting the rules about how products and services are becoming inseparable. Second, technology forecasting and technology management strategies serve as a basis for exploring the impact of a breakthrough technology such as digital printing. Understanding these methodologies provided a foundation to approach expert thinkers with the vision of a totally digital supply chain. Section 17.3 speaks to the fact that there are limitations to mass customization. Such limitations may be process oriented or technology oriented. For example, not everything about a product must be customizable and a production batch size of one may be the ultimate example of mass customization; however, it is not a requirement. Section 17.4 identifies three requirements for mass customization that are met with digital printing. The need for speed, the need for seamlessly flexible automation, and the need for integration throughout the order-to-delivery process are explored. Section 17.5 reinforces the point that product life cycles in the soft goods industry are becoming shorter and shorter. Coupling that with the fact that consumers want more individualized products means that such technologies as digital printing are positioned to capitalize on the changing market expectations. In Section 17.6 reference is made to such demands as time compression, speed to market and mass customization that are currently placed on the soft goods industry. The importance of technology forecasting is reviewed as it relates to these demands and how mass customization using digital printing may cause a reorientation of the supply chain. Section 17.7 provides an overview of how supply chains are ordered. An analysis of traditional printing supply chains is used to set the stage for the section that follows on digital printing supply chains. The key point in Section 17.8 is that if digital printing is to be used for the customization of products, decisions must be made closer to the point of consumption and the responsibility for the coloration of the fabric must shift.

An overriding theme in this chapter on the use of digital printing for mass customization is that one must look beyond the current state of the technology and/or the supply chain strategies that might employ it. There are gaps between the digital process technologies that have been developed and the 'digital islands' that have been created. There are opportunities to integrate the digital islands and this serves as the basis to think in terms of a totally digital supply chain. Since digital systems are not as sensitive to changes in product configuration, a digital supply chain should not have the same constraints that exist in a traditional physical product supply chain. The last section is dedicated to the future. Current developments promise to improve the efficiency and lower the cost of digital printing. Not only will digital printing allow for the customization of individual print patterns, it will eventually drive the development of the mass customization of solid colors using digital technology.

17.2 From craft to mass production to mass customization

Prior to the industrial revolution, manufacturing was considered a craft. Products were typically custom made to meet the needs of a particular individual. Even though many products were similar, parts from one product could not necessarily be interchanged with the same parts on another product. Since products tended to be relatively expensive, access was limited primarily to the upper class or aristocracy. With the advent of the industrial revolution and the concept of interchangeable parts, like products began to be produced in large quantities and were made available to the middle class. Because of the large production quantities of like products, the costs were low enough that they became affordable for most people.

The concept of interchangeable parts relates more directly to hard goods even though the soft goods industry also adopted the principles of mass production. In the soft goods industry finished garment parts are not yet totally interchangeable; however, large quantities of the same style will be cut and assembled as a group. While it is not practical to remove a component from a finished garment and reattach it to another garment, any component in a batch of garments ready for assembly can often be used on any of the garments in that batch. In addition, many of the components, which are also referred to as 'cut parts', can be used on multiple sizes of the same product.

Mass customization has emerged as a practice that combines the best of the craft era with the best of the mass production era. Not to be confused with custom-made, mass customized products may still be manufactured in relatively large quantities; however, each item might be slightly different based on the needs and desires of the individual end customer. Joe Pine (1993) refers to the goal of mass customization to be to provide enough variety so that the wants of the consumer are satisfied, whereas the goal of mass production was to produce at sufficiently low enough cost so that everyone could have one.

Prior to the 1980s, the mass production system dominated the soft goods industry. It was characterized by large batches of product that moved slowly through the manufacturing process. Huge inventories were carried in raw materials, work-in-process and finished goods. As a result, lead times were extremely long and commitments for delivery anywhere along the supply chain could be months. Even the sewn product manufacturers operated on a 12–16 week rolling forecast. Relationships between players in the supply chain were often adversarial and companies operated independently of their suppliers as well as of their customers. At the end of a selling season it was common for manufacturers and retailers to markdown leftover inventory.

In 1986 the concept of Quick Response was introduced to the soft goods industry. It was the industry's first collaborative attempt to better manage the supply chain linkages between manufacturers, their customers, their suppliers and their suppliers' suppliers. Such technologies as EDI (Electronic Data Interchange) and bar coding were intended to improve the accuracy of data and information flows through the pipeline. Instead of adversarial relationships, Quick Response called for partnerships between the retailers and their suppliers. Through better information flows, retailers could count on reduced lead times from their suppliers and better assure that the right product would be available at the right time. Even today, many companies continue to focus their efforts on SCM (Supply Chain Management).

During the early 1990s agile manufacturing was introduced as a strategy to help the United States regain its position as a world leader in manufacturing. Japan, for example, had taken considerable market share from US companies, particularly in the automotive and electronics industries. Agility further refined the concepts taught by Quick Response, JIT (Just-in-Time), and lean manufacturing and, according to Goldman (1997), was the collection of best practices and trends that were already underway in some of the leading US companies. Through the use of information technology, flexible automation, a knowledgeable work force and team-based short cycle manufacturing, manufacturers would be better able to respond to the needs of individual customers.

In 1991, mass customization was introduced in the literature as an example of agile manufacturing (Nagel *et al*., 1991). It was not, however, presented as a requirement for a company to be considered 'agile'. Since Pine's (1993) book on the subject, mass customization has become an established business practice and is now a topic that is discussed in almost all work that pertains to product development or supply chain management.

A study of the shift in supply chain strategies from the batch and queue system to Quick Response to agile manufacturing to mass customization reveals several trends. Information is becoming instantly accessible. Production batch sizes and minimum order quantities are getting smaller and in many cases it is possible to produce a single item cost-effectively. Product differentiation is increasing exponentially with the end consumer having more input into the configuration of the finished product. The 'order to delivery' cycle time is often expressed in terms of hours instead of weeks or months.

17.3 Limitations of mass customization

The ability for manufacturers to offer mass customization is limited by their ability to get consumer information to the 'workplace' doing the customization. Mass customization is also limited by the extent to which production workers have been cross-trained and empowered to accept responsibility for the manufacturing and 'customization' process, so that they can accurately respond to those needs. In addition, manufacturers are constrained by the lack of available technology that can be reconfigured quickly, easily, and cost effectively to meet consumer needs.

On the other hand, mass customization does not mean that everything about a product is customizable. This may have been true in the craft era, and may still be true for some products, but it is not true for mass customization. Pine says that 'variety in and of itself is not customization – and it can be dangerously expensive'. Customizable features must include only those things the customer determines are important and the customized products should not necessarily cost any more, even though research shows that many people are willing to pay more for customized products that are delivered quickly.

Information technology and automation play a key role in mass customization in that they create the linkage between a customer's preferences and the ability of a manufacturing team to construct products based on those preferences. In the case of apparel, ink jet printing technology offers the potential for color preference to become a customizable feature. There are other product features, such as garment fit, that are also desirable as consumer options. Because technology development is an ongoing process, product features that are not presently customizable can become so when affordable technology is developed that makes it possible.

The selection of fabric color at the individual garment level (which includes fabric print specification) is an area that currently offers little opportunity for mass customization. The primary reason is that to do so requires the production of 1 to 1½ yards of individualized fabric. This requirement is dramatically different from the way in which traditional textile production technologies have been developed.

Sewn products manufacturers typically commit to fabric purchases months in advance of their receipt at the production plant and they are required to make yardage commitments and issue purchase orders for fabric by color and/or print design. It is also a common practice for textile producers and fabric finishers to require minimum purchase quantities of 1000 yards or more because until now it has not been economical to dye or print small lots of fabric.

Digital technology provides an opportunity to shorten the lead-time on precolored fabric purchases and minimize the amount of raw materials inventory that must be carried by sewn product manufacturers. In fact, digital technology is already being applied to some of the pre-production processes associated with color application.

Mass customization of printed garments will require the use of digital printing technology even though the reverse is not true; i.e., the implementation of digital systems can be accomplished as a replacement for current fabric printing technology without the need to implement a mass customization strategy. The primary digital printing focus is on ink jet technologies because ink jet allows the direct application of dyes and/or inks to the textile substrate without the need for an intermediate step in the process. It is also anticipated that this technology will shift some of the responsibility for fabric coloration from textile manufacturers and converters to apparel and other sewn products manufacturers.

17.4 Time, technology, and connectivity

The primary focus of this section is on the technology management issues surrounding the use of digital printing for the soft goods industry. Therefore, it is essential to explore the extent to which direct digital printing fits the description of enabling technologies for mass customization and personalized products.

Companies that can accept input from customers in the design of their products and can manufacture and deliver to customer requirements in a very short period of time at a cost close to mass production methods will create tremendous new opportunities to capture market share. This customer input might be in the form of color preference, personal body measurements, print design, fabric type, garment features, or price point. Stan Davis and Christopher Meyer (1998) state that 'Connectivity, Speed, and Intangibles – the derivatives of time, space, and mass – are blurring the rules and redefining our businesses and our lives. They are destroying solutions, such as mass production, segmented pricing, and standardized jobs, that worked for the relatively slow, unconnected industrial world.' They state further that 'Speed means a shift from relying on prediction, foresight, and planning to building in flexibility, courage, and faster reflexes.'

Souder and Sherman (1994) put mass customization in the context of technology-based challenges by asking two questions. 'How can organizations make their products more responsive to changing customer needs?' and 'How can organizations adapt their operations (manufacturing or service and distribution) so that process technology pays no quality penalty for the speedier deliveries, small order quantities, and reliable delivery schedules?' The implications of these two questions are tremendous. In the context of digital printing, organizations could use the technology to potentially respond to whatever the current color combinations or fashionable print designs happen to be. Because the printing process uses a digital data stream from input to output, the system is indifferent to production quantities. After the designs have been created, a production order for 1000 yards of one print is not considered to be different from one yard each of 1000 different prints.

Suzanne Berger refers to the 'convergence of future consumer preferences, market forces and technological opportunities' as the drivers that will cause some industries to implement 'totally flexible' production systems (Berger *et al.,* 1991). She refers directly to: 'custom-tailoring of products to the needs and tastes of individual customers'. Again, direct digital printing can enable the production of individualized products.

Tom Peters (1991) states that among other things, successful firms will be 'oriented toward differentiation, producing high value-added goods and services, creating niche markets'. John Seely Brown (1997) says that 'technology will become so flexible that users will be able to customize it ever more precisely to meet their particular needs – a process that might be termed "mass customization".' A potential digital printing market that has been discussed with representatives of several retailers involves the introduction of a line of designer blouses. Each blouse would be digitally colored with a 'limited edition' print that is signed and numbered by the artist/designer. Assuming that high-end fabrics such as 100% silk are used and that the garment construction is currently fashionable, additional value is created because each blouse would be uniquely identified and the supply would be controlled.

To put it yet another way, Handfield and Nichols (1999) contend that 'the second major trend facing organizations today is the demand for ever-greater levels of responsiveness and shorter defined cycle times for deliveries of high-quality goods and services.' They also say that the only companies that will be successful are those that have the ability to 'mass customize'. And finally, the authors of *Blur*, who state that the rate of change today is so rapid that it is only a blur, make the following claim:

> It used to be one size fits all. Now, Porsche says it never makes the same car twice. Whatever your offer, you must tailor it each and every time, with the needs of the individual buyer or user in mind. Cheeseburgers, hotel rooms, pants, software programs, office chairs, retirement plans, skis, kitchen appliances .... Today, every offer, no matter its nature, can be customized, along many dimensions (Davis and Meyer, 1998).

17.5 Product life cycles

The result of the convergence of time, technology, and connectivity is that companies are required to introduce products more frequently with shorter expected product life cycles. Also, the days of mass production characterized by huge volumes of identical products have given way to strategies that call for individualization of products made in arbitrary quantities. Traditional manufacturing techniques are being challenged at the same time that technological innovations are providing alternative mechanisms for meeting customer expectations. As product life cycles become shorter and the volume demanded of each product becomes smaller, the need for technologies that are designed for shorter runs and smaller quantities will become greater. Direct digital printing is one response to the need for short runs of printed fabric and it is already being used on a limited basis for the production of new print designs.

The demands of consumers and the roles played by manufacturers are not unique to the soft goods industry; however, the soft goods industry is more affected by changes in consumer tastes and whims than most other industries. Many of the end products also have an extremely short product demand life span. To achieve a leadership role and to respond effectively, the textile and apparel industry must innovate. Manufacturers and suppliers, including machinery and equipment vendors, must recognize the trends of their customers and the expectations they have for quality, personalization, service, and delivery. They must identify the strategic directions, including technologies, required to meet these expectations.

17.6 Forecasting the opportunities

Time compression, speed to market, and mass customization are terms that are commonplace in today's globally competitive environment. What is not commonplace are the integrated solutions to these challenges. In the case of direct digital printing, the first applications have been substitutions for other printed fabrics. The potential to replace dyeing for solid colors or Jacquard fabrics is not as feasible at this time.

The questions that were posed in the opening section can possibly be better answered with a more complete understanding of technology management and the various methods of technology forecasting that have evolved. Technology forecasting can be useful to steer development programs toward innovations that could either reduce costs to increase profits, or provide new services for customers. Technology forecasting can also be used to help identify new business opportunities, and may lead to a modification of corporate goals.

The desire to be different and the desire to be unique have a major influence on the demand that individuals in the US have for clothing. If it were possible to predict consumers' future wants and expectations, companies could align their technology development and implementation strategies with the expectations of their customers.

Until a viable business practice is established, it is appropriate to question the potential impact of digital printing on the soft goods supply chain. Kurt Salmon

Associates (KSA) completed a study of mass customization in 1997 (KSA, 1997) and concluded that the early adopters of mass customization technologies will have an advantage over their competitors. The study also showed that the manufacturer's profit on a seasonal garment sold through department stores can increase from 8.6% to 18.1% without affecting the retailer's gross margin. When comparing fashion garments sold through department stores, the manufacturer's profit increases from 6.9% to 17.9%, again without impacting the retailer's gross margin.

In addition to reviewing the results of the KSA study, an analysis of technology forecasting is appropriate. Technology forecasting can be used to determine not only when or if digital printing will have an impact, but how and to what extent it will impact the industry. It can also be used to predict what may happen to the competitive environment of the organizations that conduct business in the soft goods supply chain.

The most common form of technology forecasting is trend analysis. It is easy to understand and generally assumes that the future will be an extension of the past. As with most processes, there are simple as well as elaborate approaches to conducting trend analysis (Cetron, 1969; Martino, 1993).

The easiest trend analysis method to apply is trend extrapolation. It is also popular because it is relatively inexpensive to conduct. By mapping the past graphically, the future can be predicted through an extension or 'extrapolation' of the past. It is simple and inexpensive but should not be considered reliable beyond a relatively short time period. It would be impractical to rely on this method to predict technology events a decade in the future. In fact, decisions that look beyond a one-year time frame should be made using an alternative forecasting method (Martino, 1993). Trends in the soft goods industry include:

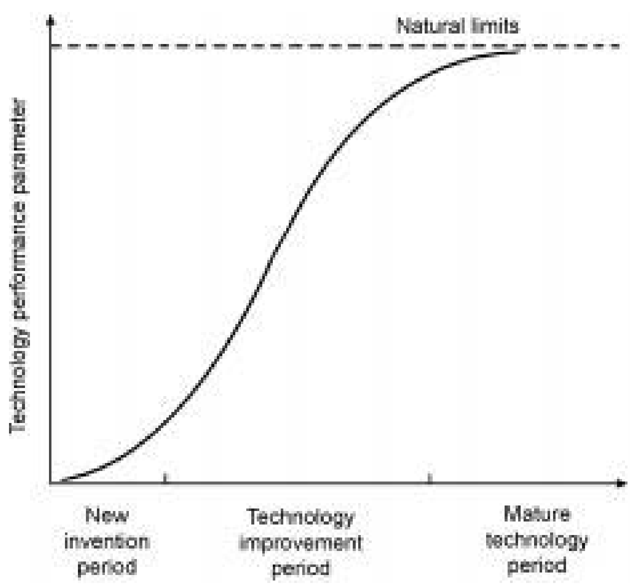
- Shorter product life cycles
- Lower desired inventories throughout the supply chain
- More differentiated products
- New forms of retailing such as television and the Internet
- Increased use of information technology
- Reduction in time to market
- Marketing to a customer of one.

Time-series estimation goes one step further in that it attempts to account for the variations in the slope of a trend line over time. For example, it can be used to identify specific trends such as seasonal variations. It is more complicated than trend extrapolation and often requires the use of a computerized statistical analysis package. A common projection using time series analysis is the forecast of sales by quarter.

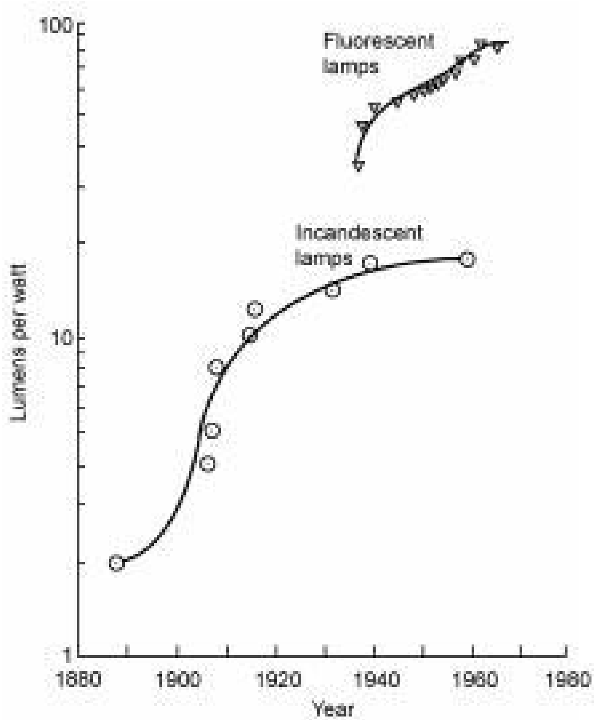
Regression analysis can also be used for time series estimation; however, it is especially useful when more than one variable is required to explain the present state or predict the future state. Regression can be used for non time-series forecasts as well. It has become very popular because of the availability of such computer programs as SAS and Statgraphics and because it simplifies understanding of more complicated forms of trend analysis such as econometrics.

S-curves have been used to graphically illustrate the growth pattern of new technologies. Fisher and Pry (1972) used them to show that the rate of acceptance of new product introductions is generally slow at first. This slow start is followed by a period of fairly rapid growth or technology advancement as the new products penetrate the marketplace. Once market saturation occurs and the product has reached the last stages of its life cycle, growth and advancements taper off (Fig. 17.1).

Anderson and Tushman (1997) refer to the introduction of a breakthrough product or technology as a *technological discontinuity*. A technological discontinuity triggers a technology cycle that begins with an *era of ferment* during which the new technology 'displaces its predecessor during an *era of substitution*'. Following the discontinuity but overlapping the era of substitution is an *era of design competition* where more refined versions of the technology are introduced. 'The emergence of a dominant design marks the end of the era of ferment and the beginning of a period of incremental change' (Anderson and Tushman, 1997). During this time 'the rate of design experimentation drops sharply and the focus of competition shifts to market segmentation and lowering costs (via design simplification and process improvement)' (Anderson and Tushman, 1997). This change corresponds with the last stages of the life cycle of a technology, which would in turn be followed by another technological discontinuity. Figure 17.2 provides a graphical view of the advancements in



17.1 Technology S-curve, general form (Betz, 1993).



17.2 Technology S-curve for progress in lamp technology (Betz, 1993).

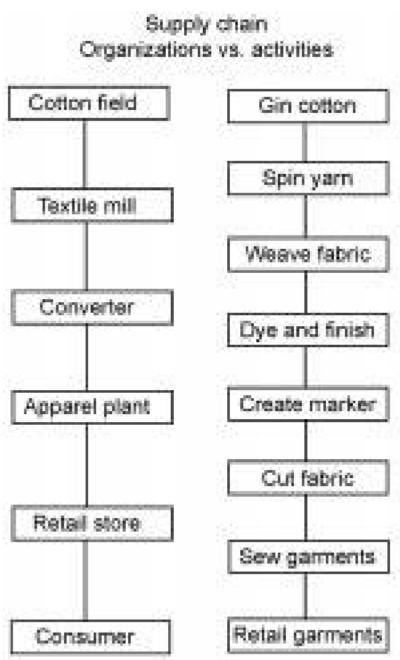
lamp technology following two breakthroughs, one in incandescent lamps and the other in fluorescent lamps.

While digital printing is currently in the very early stages of its life cycle in the soft goods industry, ink jet printing has entered the era of ferment for the office printer market. The market 'is expected to mature in the next few years' (I.T. Strategies, 1999). Ink jet printers have replaced laser printers for many applications and the era of design competition has also begun. Ink jet offers lower cost, a smaller footprint, and greater flexibility than laser printers. Since its capability is still somewhat limited for textile substrates, it is not yet an accepted substitution in the soft goods industry for analog printing methods (Clark, 1999).

Believers in trend analysis recognize that history can and does repeat itself, that business is cyclical, and that problems encountered in one industry are eventually experienced in another. Historical analogies is the formal name given to the method of trend analysis that projects the future based on a study of past practices in other industries and draws inferences from the lessons learned (Cetron, 1969). Digital printing in the soft goods industry should track closely what has happened in the paper industry. Analog technologies have been replaced by digital technologies and ink jet is now the dominant technology. A similar substitution should occur as the soft goods industry transfers learning from the paper printing industry.

17.7 Traditional supply chains

Supply chains are characterized by the movement of goods from the initial raw materials provider, through one or more manufacturing processes, distribution, retailing, and delivery to the end consumer. Many of the terms used to identify a supply chain are interchangeable; however, some distinctions should be made. 'Supply chain', 'industrial value chain', 'value-added chain' and 'integrated supply chain' are used interchangeably. Each of these terms may be used to refer to a set of organizations that collectively and sequentially bring a product from raw materials to the end consumer, or may refer to the set of activities required to produce a product and deliver it to the end consumer. An individual organization may be responsible for multiple activities that get captured as a single step in a supply chain. At other times each activity will be identified as a separate step. Figure 17.3 illustrates these two scenarios for a soft goods supply chain: one that has been segmented into organizational functions; and one that has been segmented into the activities that are performed. Depending on the company, 'supply chain' can mean either the set of organizations of which it is a part or the activities that it conducts.



17.3 Soft goods supply chains.

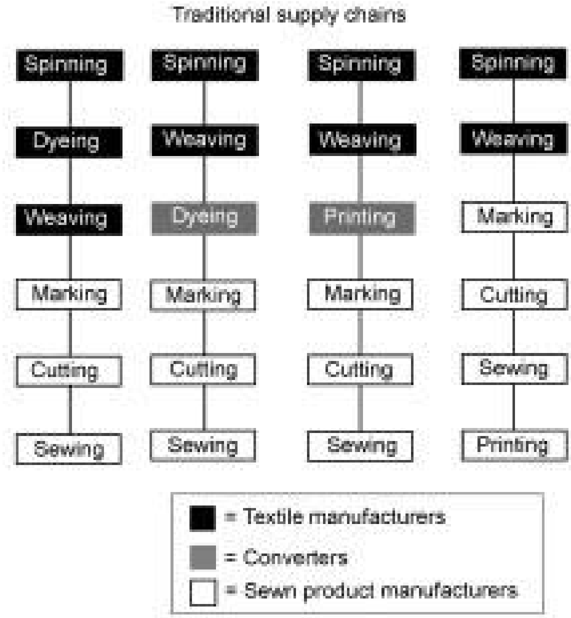
A tremendous amount of work has been done to track the flow of materials and information through a supply chain. The most notable in the soft goods industry was accomplished through a project known as DAMA (Demand-Activated Manufacturing Architecture). This project resulted in the creation of process maps for such products as men's cotton slacks (DAMA, 1995), bed sheets, and nylon supplex parkas. 'These process maps included the movement of the goods and the conversion steps through which the goods passed, the information behind each step, quality checkpoints, and time elements for each step' (Kuglin, 1998).

The soft goods industry supply chain consists of fiber producers, yarn manufacturers, fabric manufacturers, fabric finishers, apparel and other sewn products manufacturers, wholesalers, retailers, and consumers. The type of organization that will control a particular step in the chain depends on the finished product that is being made. For example, for a woven product such as men's slacks, some of the significant supply chain steps and major players could be as follows:

- Fiber producer s: Invista, KoSa (formerly Hoechst-Celanese)
- Yarn manufacturers: Dixie Yarns, Parkdale, Unifi
- Textile manufacturers: Burlington, Milliken, Greenwood Mills
- Fabric finishers: Cherokee, Cranston Print Works, Lortex
- Apparel manufacturers: Russell Corp., Levi Strauss, VF Corp.
- Retailers: Dillards, J.C. Penney

While the processes in the chain are somewhat distinct, clear boundaries do not always exist to differentiate companies that are traditionally called 'textile manufacturers' from those that are referred to as 'apparel manufacturers'. For example, Russell Corporation, a major supplier of knit products, will purchase fiber but will spin its own yarn, knit its own fabric, dye the fabric, cut the fabric into components, and sew the components into finished garments for distribution to its customers. Other knitwear manufacturers will purchase yarn, knit and dye the fabric, and cut and sew garments. Others will buy the fabric from which they cut and sew finished garments. Manufacturers of woven garments typically outsource the manufacturing and finishing of the fabric and focus on cutting and sewing the fabric into finished garments.

When considering the investment in digital printing technology, fabric finishing becomes an even more important step in the soft goods supply chain. This step includes fabric coloration, which can involve dyeing or printing the fabric prior to cutting it into component parts. Figure 17.4 represents traditional supply chains for making and coloring fabric and sewing the fabric into finished garments. The black boxes represent activities that are typically performed by textile manufacturers; shaded boxes represent activities that are typically performed by either converters or textile manufacturers; and white boxes represent activities that are typically performed by apparel and sewn product



17.4 Alternatives for coloring and sewing fabric.

manufacturers. At Russell Corporation, all of the activities (knitting replaces weaving) shown in the second column are performed as a part of the internal supply chain.

Companies today should be aware of the challenges affecting the supply chains of which they are a part and the changes that can impact their internal supply chains. For example, digital printing has the potential to significantly alter some segments of the soft goods industry supply chain. While some organizations may consider digital printing as merely an alternative technology for rotary screen printing, others consider it a 'breakthrough' technology that has the potential to be applied to new families of mass customized products.

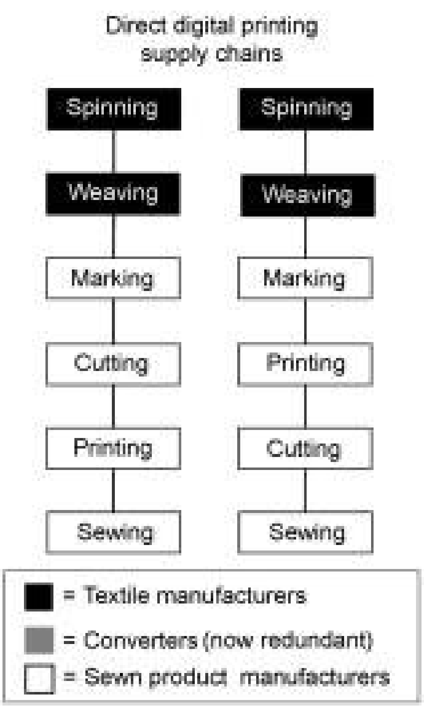
Wheelwright and Clark refer to breakthrough products as those that 'depart significantly and fundamentally from existing practice'. Furthermore, breakthrough products 'may introduce highly innovative product or process technology, open up a new market segment, or take the business into a totally new arena' (Wheelwright and Clark, 1995).

A digitally printed line of limited edition blouses would definitely enter into a niche market and a company like Brooks Brothers could market digitally printed ties as an extension to its custom-made dress shirts. Naturally, the market for these products would be limited to customers who are less sensitive to price, although it is common for new product innovations to be expensive at first and then to decrease in price as demand rises. It is also common for breakthrough or disruptive technologies 'to be used and valued only in new markets or new applications; in fact, they generally make possible the emergence of new markets' (Bower and Christensen, 1997).

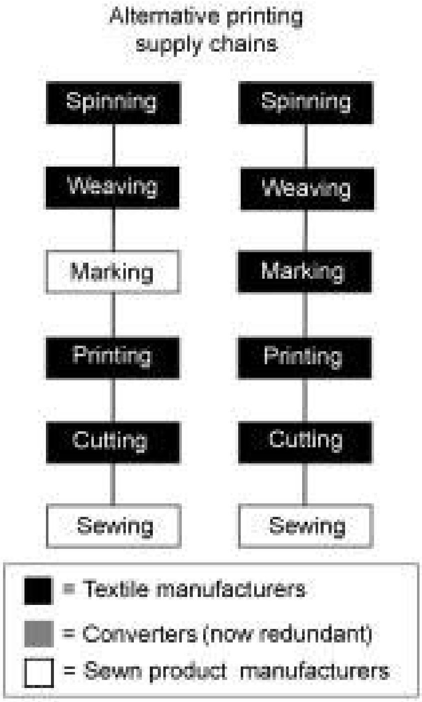
Betz's research (Betz, 1993) shows that 'major changes occur in an industrial value chain when basic inventions are discovered and introduced into a sector of the industrial value chain.' In the case of digital printing, such products as the mass customized, limited edition blouses can be manufactured more cost-effectively by shifting the responsibility for printing to the sewn product manufacturer. This transition is a major departure from traditional supply chain practices since fabric is usually printed before it is stocked at the apparel plant.

17.8 Direct digital printing supply chains

Figure 17.5 diagrams two direct digital printing supply chains. One involves printing on cut parts and the other involves printing prior to cutting. Printing on cut parts can also be accomplished using belt screen printing technology. In both cases the responsibility for printing shifts from the textile manufacturer and/or converter (refer to Fig. 17.4) to the apparel manufacturer. The primary reason for shifting the printing activity is that printing fabric after the marker is made provides additional benefits.



17.5 Printing on cut parts versus uncut cloth.



17.6 Textile mill responsible for printing.

Markers are traditionally made by the sewn product manufacturer and typically are not generated until a request for finished product has been made. Even so, responsibility for printing could stay with the textile manufacturer, and responsibility for cutting or for cutting and marking could shift from the sewn product manufacturer to the textile manufacturer. Figure 17.6 illustrates these supply chain configurations. The decision regarding where to mark should be made based on who has responsibility for fabric utilization and the point of control for order information. The objective of this type of supply chain reorientation is to respond quickly and efficiently to the wants of the customer.

The supply chains detailed in Figs 17.5 and 17.6 provide a preliminary look at where direct digital printing might fit in. As more and more processes make use of digital technology, 'islands of digitalization' are being created. The extent to which these 'digital islands' are integrated will also drive the type of information systems needed to support a 'totally digital supply chain'.

It is becoming more obvious that batch size becomes less important as supply chains become more digital. In other words, the point at which a product in the supply chain moves from an analog process to a digital process is the point at which batch size or production quantity is no longer a constraint. Research has demonstrated how digital printing, along with other digital process technologies, supports this claim. This is also an indicator of the direction that digital printing is likely to take in the soft goods industry.

17.9 Future trends in the digital supply chain

By now, it should be apparent that supply chain processes are incorporating an increasing amount of digital technology. Just as ‘islands of automation’ were being created in US factories during the 1970s and 1980s, ‘digital islands’ are being created in supply chains today. These digital islands are changing the rules of supply chain management and, in some cases, are causing a reorientation of supply chain processes. The movement towards mass customization that has been underway during the nineties will eventually give way to another supply chain strategy. This strategy will be called the ‘digital supply chain’.

A digital supply chain is created when the process steps within the chain have been converted from analog functions to digital functions and the digital functions have been integrated into a continuous stream of product data. Since digital processes are readily reconfigured, they are not constrained by batch size. The result is a supply chain that is not constrained by batch size or production quantity. Mass customization technologies will play a significant role in the digital supply chain because they too are indifferent to batch size or production quantities.

For example, body scanning is changing the way brands and retailers think about fit and the way they think about standard sizing. It is an enabler for digital product development for mass customization, but also has applications to the ready wear market. In the future, fit models for every size will be scanned and custom patterns will be generated for each of the fit models. The result will be set of patterns that more accurately map the variations in size from small to large. This will also allow the segmentation of a population, a brand, or a group of retail customers or into a set of standard sizes that more accurately represent the target market.

In fact, the entire product development process will become digital. From yarn formation to fabric formation, to designing silhouettes to draping digital fabrics onto the silhouettes and applying color or print designs, the process will not require the conversion to physical samples and will be accomplished in 3D. Product Development Management (PDM) packages will contain patterns, cost sheets, bills of materials, manufacturing specifications, fabric specifications, quality standards, and in some cases, color specifications and printing instructions that can drive digital printing machines. The entire data set will be distributed and accessed worldwide.

Simulations of human movement are beginning to have the appearance of near reality. It is not a big stretch to recognize that we will be able to scan a physical body (consumer) and from the scan data create a virtual, morphable body model and drape digital clothes on it. The digital clothes will be converted to the physical clothes only when the consumer is satisfied with the fit, design and performance of the product.

Garments will be designed in 3D using body scanning technology and automatic pattern generation. Color and print will be applied and converted using digital technology; however, the colorants will be produced in such a way that pre- and post-treatment of fabrics will not be required other than a heat set. The same set of colorants will work on silk, cotton or polyester and will have the same appearance and the same performance results. In other words, light fastness, color fastness and wash fastness will be equivalent to existing standards. This will augment existing digital printing technology such that solids can be produced in very small quantities, very efficiently and in environmentally acceptable ways.

The same type of colorants that will revolutionize the coloring of solid fabrics will also allow sewing thread to be colored on demand. One can imagine a device that would unwind, color, and rewind a cone of thread without the need to vat dye in large quantities. It will also allow color decisions to be made much closer to the point of consumption.

The technology of ink jet printing and the strategy of digital product supply are already in practice to some extent in the soft goods industry. As the chemistry evolves and the performance of the application technology improves, machine instructions will be generated at the point of design and distributed digitally during the order fulfillment process. The result will be a much more responsive supply chain that allows consumers to order customized products that will be distributed digitally and converted locally within very short time frames.

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18 Just-in-time printing

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18.1 Introduction

The printed textile market is a competitive arena that requires considerable risk and investment in time and inventory via the conventional screen print process. As the soft goods industry has become increasingly reliant on the production of smaller quantities and shorter manufacturing cycles, industry leaders have looked to alternative methods for creating product. Within this environment a digital approach to textile printing has been recognized as a viable option for producing printed textiles. As an emerging manufacturing method, digital textile printing has also been identified as a key process that supports the goal of 'Just-In-Time' production within the sewn products industry. This chapter will examine the adoption of digital inkjet technology for just-in-time printing and will discuss significant technological developments and issues that support successful implementation within the manufacturing environment. Before launching into this discussion, it is important to have a general understanding of the 'Just-In-Time' concept and the role of digital textile printing within this manufacturing strategy.

18.1.1 The just-in-time concept

Just-in-time or 'JIT' is familiar terminology within the sewn products industry and is generally applied to a supply chain scenario in which product is manufactured and delivered in a timely fashion and in direct response to market demands. While the term is often used in reference to manufacturing specifically, the successful implementation of JIT also relies on strategies that support supply chain visibility and management. These strategies involve data collection and analysis at the retail level and various points along the supply chain; communication of demand for the product and its specifications to manufacturing; communication of demand for raw materials and parts among supply chain partners; logistical control from raw material through product delivery; and product monitoring and quality control throughout the manufacturing process.

In practical terms, in order to deliver the right product to the consumer 'just-in-time', the retailer must have knowledge of both current inventory and consumer demand. The retailer must be able to communicate their inventory needs to the manufacturer, and the manufacturer must have the ability to rapidly respond, providing the specified product at the agreed upon quality level. Throughout the supply chain, there must be a shared awareness of manufacturing capabilities and limitations and manufacturers must maximize their flexibility so that they can rapidly adjust to changing needs within the just-in-time environment.

As you ponder the concept of 'manufacturing flexibility' it is important to remember that the sewn products supply chain is relatively complex. Fabric embellishment, including printing, is merely one step in a long list of processes that turn raw materials into finished fabric, garment, or fabric structure. In the past, this complex supply chain has largely been driven by manufacturing and within this scenario, the manufacturer analyzed trends and attempted to predict consumer desire for product. The manufacturer designed the product according to their trend information and offered it for sale to the retailer. The retailer selected from available styles and filled their stores accordingly, hoping that they purchased the right product, in the right color or print, in an appropriate quantity. With the introduction of 'just-in-time', there has been a shift from a manufacturing driven economy to a demand driven economy. Within this environment, flexibility is paramount as the manufacturer must respond to, rather than dictate, product need at the retail level. With this in mind, we can begin to look at the significance of the digital print process and the role of digital technology for 'printing on demand'.

18.1.2 Printing on demand in the digital environment

The development of digital processes has been key to the implementation of 'on demand' manufacturing methods, and as we begin to examine the adoption of the digital print process it's helpful to review Wantuck's (1989) explanation of JIT. He describes JIT as a production strategy and specifically notes the link between quality and productivity, indicating that 'The JUST-IN-TIME Strategy includes seven principles which can guide us toward world-class productivity. It requires that we:

1. Produce to exact customer demand
2. Eliminate waste
3. Produce one-at-a-time
4. Achieve continuous improvement
5. Respect people
6. Allow for no contingencies
7. Provide long-term emphasis.' (Wantuck, 1989, p. 11)

Although each of Wantuck's seven principles is significant, we can highlight the first three as we look at the digital textile printing process specifically. As compared to analog or 'conventional' printing, the digital print process provides the opportunity to print very short lengths of cloth according to individual customer specifications and changing market demands. It reduces waste by minimizing design setup and eliminating costly and time consuming changeover for new designs or colorways. It allows for multiple product printing and very quick change of print, colorway, and/or design element.

If we look to the remaining four principles, digital textile printing is still an emerging process that offers the opportunity for early adoption, growth and continuous improvement through experience and technological development. It respects people by harnessing the creativity of individuals and extending the potential for unique designs and printed effects. By eliminating waste and increasing production flexibility digital printing reduces the need for contingency plans including carrying excess inventory. Finally, the adoption of digital printing is a long-term strategy that can be implemented in stages with the ultimate goal of providing prints on demand. Many manufacturers have started their exploration of digital printing by adopting the technology for sampling and product development. As they gain experience and confidence in emerging solutions, they can begin to look at digital printing as a manufacturing tool.

As we examine the manufacturing benefits I've noted, they are largely the result of the digital approach. In the digital world it is possible to create and hold design information in a form that is easily retrieved and altered. As order information is communicated to the manufacturer, prepared for print greige goods can be converted to printed cloth. Design information can be customized using CAD technology and precise lengths of fabric can be specified at the print station and produced according to individual order specifications. Orders can be batched at the printer for efficiency and ease of processing. With this background in mind, we can begin to examine how available technology and ongoing development will enable successful adoption by the soft goods industry.

18.2 Enabling the process

In its infancy, digital textile printing was predominantly a sampling or prototyping technology. While implementation of digital printing for this purpose offers considerable benefits, there are great rewards to be reaped by organizations and individuals that can successfully implement a process for printed fabric production. Our industry has been aware of these benefits for some time. However, we have been slow to adopt the approach for production. What is the reason for this? The answer to this question can be found if we examine the nature of supporting technology and processes.

18.2.1 Supporting technology, processes, and materials

On the surface, supporting technology would appear to refer specifically to printer hardware and software. However, the development of printed textiles involves a range of technologies, processes, and materials that support a series of production stages including design and product development, printing, fabric preparation and finishing, cutting and product assembly.

Product development

The textile printing process begins with concept design and imagery development. During this stage of product development, designers research the marketplace and trend resources for design inspiration. They develop prints and color palettes based on their research, keeping in mind their target customer and end product requirements. This step in the process has been digitally driven for some time through the use of CAD technology. Hand-painted designs are photographed or scanned and edited by designers utilizing off-the-shelf and industry-specific graphics programs. As designers have become more fluent in the use of CAD and the technology has become more intuitive in nature, designers are increasingly developing artwork directly in the CAD system. The advent of digital photography has even enabled a truly digital approach as artists develop concepts directly from digital resources.

While conventional print methods have also been supported through the adoption of CAD for product development, the digital print method is *reliant* on digital designs to feed the process. The color reduction and separation process that is required for the engraving of screens has become almost exclusively a digital process. Although color reduction and separation, as well as the preparation of pattern repeats, are often undertaken for digital prints as part of a sampling and/or color management strategy, they are not a requirement of the digital print method. Even so, the design information must be delivered to the inkjet printer in digital form. The design file is often prepared and supplied in such universal formats as .tif or .jpg files that hold the pattern and color information the printer software requires for image processing and color management. These files are then interpreted for output at the printer by specialized software programs for color management and raster image processing or 'RIP'.

The digital design environment provides a wealth of flexibility that is key to the JIT scenario. As long as the design remains digital, it is possible to make quick changes to pattern or coloration. Digital designs are easily stored or archived and retrieved on demand for production purposes. It is possible to harness such design archives, so that customers can review designs from previous lines or seasons and update or reorder as the market dictates. In the digital print environment it is also possible to create highly unique designs that illustrate special tonal (see Fig. 18.1) or photographic detail (see Figs 18.2 and

18.1 Dahlia scarf, provided courtesy of [TC]^2.

18.3) and are almost unlimited in terms of color number and design length. There is even the potential for print engineering according to the shape of cut parts and to enhance overall product design.

Printing

There are currently a range of hardware, software, and ink chemistry solutions in the marketplace for digital textile printing. With respect to printer hardware, machines have been engineered by vendors for a variety of applications including both sampling and short-run production. Early machinery introductions were largely modified and/or re-engineered paper printing machines with specialized fabric handling mechanisms and textile specific software solutions. These machines operated at very modest speeds, typically printing well under 10 meters per hour in quality modes. This equipment was criticized as being too slow for production purposes and has predominantly been used for samples/ prototypes and for one-of-a-kind or very small-scale and fine art production. More recently introduced production-oriented equipment often features more robust print head technologies and belt fabric handling mechanisms. While these technological introductions are also engineered for vast improvements in print rate, currently available production printers continue to operate at relatively modest speeds as compared to rotary screen technology.

18.2 Rhododendron scarf, provided courtesy of [TC]^2.

18.3 Iris scarf, provided courtesy of [TC]^2.

Even so, industry leaders continue to analyze the merits of the digital method for production and question the ‘real efficiency’ of the rotary environment, taking into account practical rates for the operation of rotary machines and the amount of printer downtime required to change colors and align screens. This is noted in contrast to the high degree of production flexibility offered by the slower digital printer. While digital print rates have initially been a barrier to the implementation of JIT, there appears to be growing interest by the soft goods industry as technological advancement has occurred. This interest is highest in higher-end market areas and those that benefit from short runs, product customization and/or special effect printing such as ties, scarves, and swimwear.

What print speed is required for successful implementation of digital printing for JIT production? There is more than one vision for production printing. Some hardware developers have focused their efforts on the refinement of smaller-scale machines that can be used in multiples to meet production demands, much like the ‘weaving mill approach’. Other developers have focused their efforts toward the design of more robust, higher-speed machines that are accompanied by larger price tags. While potential adopters questioned the price and reliability of early introductions of production-scale equipment, more recent technological introductions have attracted greater interest. There is likely a place for both approaches as production requirements depend on a variety of variables including product type, market, and business model. Printing for high-end and high-fashion markets may take advantage of the substrate and ink chemistry flexibility offered by the use of many small-scale printers for production, while production for more mainstream markets and products may be suited to the efficiencies offered by larger-scale machinery. It appears that both approaches are developing simultaneously within the printing industry.

Print rate has not been the only barrier to technology adoption for JIT. The inkjet environment requires highly purified and specially formulated colorants for reliable jetting. These colorants are typically more costly than colorants for conventional print methods and early introductions to the marketplace presented issues related to nozzle clogging and recovery. Print head engineering and compensation along with refinement of inkjet chemistry for textiles have gone a long way to address this issue. Drop-on-Demand (DOD) piezo print head technology dominates the current marketplace and has also been a focus for research and development. In contrast to thermal inkjet technology, the piezo approach allows for greater flexibility in terms of ink chemistry and does not involve heating the ink chemistry, which can be at the root of print nozzle failure. Despite advances, machines will continue to require monitoring for problems and fabric inspected for quality.

As previously noted, colorants for digital textile printing are specially formulated for the inkjet process. Research and development has resulted in the development of reactive, acid, and disperse dyes for inkjet, as well as pigments. Dye-based coloring systems including reactive and acid have been the focus for early development. These colorants are highly water soluble and are more easily formulated for inkjet to obtain a range of brilliant master hues for process printing. However, the fabric pretreatment and wet finishing processes required to achieve optimal print results and enable color fixation of these dyes have been a deterrent for adoption. Even so, auxiliary equipment and service providers are now available to address these issues. Disperse dyes and pigments have been more challenging to formulate, as color chemists address issues including jettability, color fastness, and color brilliance for these chemistry types. As a result of research and development, there are now a number of vendors for these colorants in the marketplace today. The continued development of textile pigments for inkjet may provide some manufacturers with greater substrate flexibility and will ease fabric preparation and finishing requirements.

Despite the advances in color chemistry for inkjet, there is still room for development of the 'perfect ink chemistry'. This ideal solution would eliminate the need for fabric pretreatment and would enable integrated printing, color fixation, and cutting for in-line manufacturing. Although this 'ideal solution' is not commercially available, digital printers are using available colorant chemistry to print a wide range of substrates for an endless variety of product types.

Software development has also been essential to the successful implementation of digital textile printing at all levels. Unlike paper, which can be made uniform in terms of surface character and absorption, textile characteristics can vary widely. As a result, specialized software has been designed for this application to optimize color output for specified fabric, ink, and printer combinations. Software solutions can also be utilized to manage color separations and print quality for the sampling strategy. Software features may include the ability to create and manage color profiles for printing, specify a range of repeat arrangements, indicate print length and width, select designs and/or colorways for printing, specify color by screen through the use of a spectrophotometer or by entering a numerical color value, and control print quality to replicate the screen printed effect (e.g. color order, spread, fall-ons, etc.). This kind of software has become an integral part of the digital print system for textiles and cannot be undervalued. The importance of software and the idea of an integrated systems approach have been recognized by hardware and ink vendors and addressed through development partnerships and joint marketing relationships.

It is essential to note that color is the key feature for any textile product. With this in mind it is essential to be able to obtain a wide range of hues within any printing or dying system. This is possible within the spot color screen printing process as each hue is pre-mixed from a master set of colors and applied in stencil form. However, the process color printing approach utilized in the inkjet environment is a completely different procedure. In the inkjet world, colors are 'mixed on the fly' in the form of ink droplets that are selected from a master set. While a wide range of printed effects are possible as a result of this approach, early systems were criticized for limitations in color gamut and the appearance of dither, particularly in the areas of pastel and neutral tones. Technology solution providers have addressed these concerns through print head development, color number, ink chemistry formulation, and software. As a result, currently available systems have considerable capabilities and are able to produce large color gamuts and print quality that rivals the spot color approach.

Fabric preparation and finishing

For optimal print results, fabrics for digital printing must be specially prepared for the process. As with any prepared for print (PFP) fabric, the greige cloth may be scoured and bleached depending on the fiber type. This step removes oils and impurities in the fibers and ensures a clean white surface for the application of color. Fabrics for inkjet are then pretreated. Fabric pretreatment serves two purposes. Pretreatment typically involves the application of a thickener to maintain print precision and prevent color wicking. It also involves the application of chemical components such as an alkali or acid that enable fixation for dye-based printing. In conventional printing, the thickening agent and auxiliaries can be found in the print paste. However, thickening agents, binders, and alkali or acid components may cause clogging or degradation of the print head and are therefore applied as pretreatments to the PFP cloth.

The fabric preparation procedure is relatively involved and requires specialized equipment for even application and quality print results. Outside the mill environment, this step is often outsourced to service providers and can add considerable cost to the base fabric. In the JIT production printing environment, longer runs of cloth will be consumed as compared to sampling and pretreatment may take place as an in-house activity utilizing existing open-width pad or screen systems. Alternatively, smaller-scale equipment has also been developed for pretreatment application in the digital plant. Quantity and in-house processing will certainly have an impact on the overall cost structure for digital printing. However, in the fashion area product designers will look to print a wide range of fabrics and fiber types. This will continue to be a challenge to product developers and printers who will develop strategies for preparing, obtaining or stocking PFP fabrics for the inkjet process with the goal of providing quick turnaround, while minimizing inventory.

With respect to fabric finishing, a variety of equipment has been developed for the digital print process. Batch steamers have been adopted for sampling and very small-scale production purposes. However, JIT production printing will be enabled by larger-scale fixation equipment. Where digital printing exists alongside conventional rotary setups, printers may utilize existing production resources for fixation and washing. Digital mills will rely on a new generation of machinery that has been developed specifically for the digital process. This equipment includes in-line and continuous steamers, open-width washing devices, and drying technology. These machines have smaller footprints and price tags than full-scale production equipment and may be more suited to the shorter runs and more modest print rates experienced in the digital environment.

Cutting and product assembly

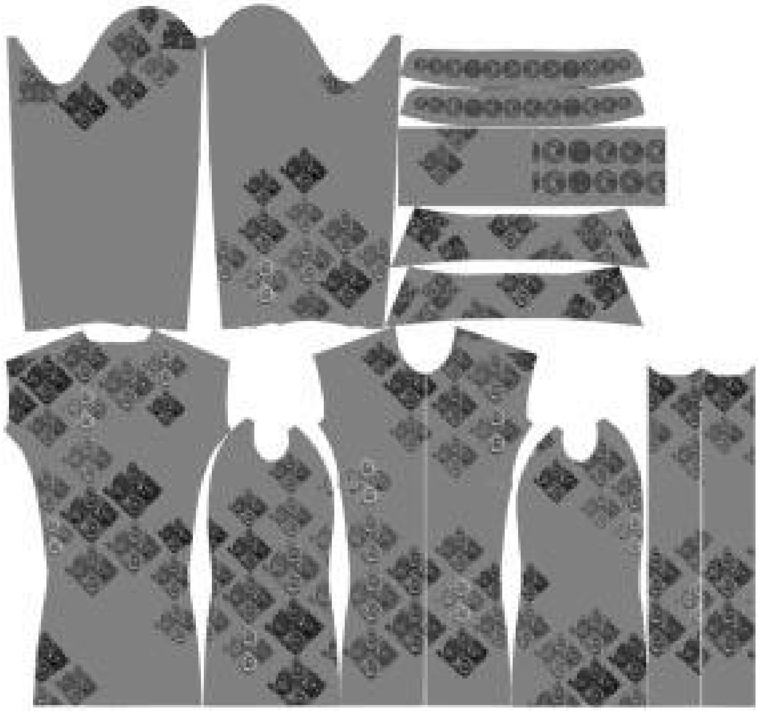
A discussion of enabling technology and processes for JIT is not complete without addressing fabric cutting and assembly. Cut and sew is part of the manufacturing procedure for most printed textile products. With this in mind, the ideal manufacturing solution would minimize the processing and skill requirements for assembly and maximize flexibility. Flexible manufacturing is a key component within the JIT supply chain. JIT printing is of limited advantage, if the fabric moves slowly through the cut and sew procedure. Single-ply cutting technology and short cycle manufacturing methods are process enablers and are well developed for sewn products. They provide an alternative to more traditional multi-ply cutting and the progressive bundle method of product assembly that result in larger quantities of work in process and reduced manufacturing flexibility.

The cut and sew process may be further enhanced for specific product types through engineered printing. In the digital print environment, the imagery may be designed to print only within the shape of the product piece and engineered for pattern matching (see Fig. 18.4). This strategy can allow for optimal fabric utilization and simplify any hand cutting requirements by providing an outline for the cutter to follow. Engineered printing may be of particular value in areas such as the custom upholstered furniture business. Hand cutting of upholstery fabrics is relatively common for custom orders and requires a considerable amount of personal training to ensure pattern matching of printed goods. Engineered printing may effectively de-skill this work and allow greater flexibility and cross-training within the cut and sew area for upholstered furniture (see Fig. 18.5).

Despite technological advances in cutting technology, mechanical cutting of engineered prints continues to be a challenge. While cutting machines with cameras for piece recognition and positioning are in existence today, the wet post-processing required for color fixation and wash-off of currently available colorants results in dimensional instability and makes the development of in-line print/cut systems challenging.

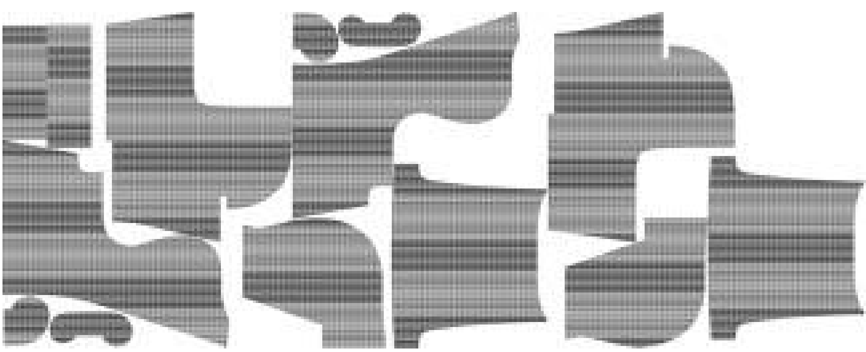
18.2.2 Technology development and integration

It is apparent that currently available technology and systems are the result of ongoing research and development efforts. When our industry first began its exploration of digital printing for textiles, development was required in diverse areas of specialty including hardware, software, and ink chemistry. Developers



18.4 Printing marker for apparel, provided courtesy of [TC]².

quickly learned that their research could not be undertaken in isolation and that inkjet printing for textiles required an integrated systems approach. The result of this thinking was the formation of development partnerships and joint marketing efforts. The introduction of the DuPont Artistri and the Reggiani Dream systems are two examples of joint efforts that have brought together expertise in areas including ink chemistry, print head technology, fabric handling, and color



18.5 A portion of a marker for upholstery, provided courtesy of [TC]².

management. The marketing partnership between Stork Digital and CAD technology provider Lectra Systems is another example of a systems approach for digital textile printing.

As technology systems have developed for JIT printing, there is increasing recognition of the need to develop more integrated manufacturing solutions. As noted in the previous sections, printing is only one step in the production of a printed textile. Fabric preparation and finishing are also required in order to obtain prints with appropriate washfastness and serviceability characteristics. Development of a new generation of equipment that addresses the shorter runs and flexibility requirements of the digital method is key to the successful implementation of the JIT approach. There is growing acknowledgement of the need for in-line and modular preparation and finishing systems that can be arranged and adapted according to specific ink chemistries and the specialized needs of a given manufacturing environment. The development of innovative ink chemistries that eliminate the need for wet post-processing may even allow for the development of in-line cutting, the benefits of which were noted in the previous section.

In addition to technology integration in the area of printers and auxiliary equipment, there has also been the development of integrated color management systems and strategies that assist the printer in reproducing color palettes specified during the product development stage. The term 'color management' does not refer to a single activity, but rather a process that involves identification of color targets or palettes and the accurate communication and reproduction of this specification through the manufacturing supply chain. Color management strategies are supported by software solutions and color measurement hardware that enable the profiling of systems and transmission of numerical color data to aid the printer with accurate color reproduction as specified by the product developer or customer. The ability to predict and control color output is essential to the just-in-time model as manufacturers are required to 'get it right the first time'.

It is apparent that technology development and integration is occurring simultaneously in a variety of areas in support of digital textile printing. As this development has taken place, conditions are becoming increasingly suited to the implementation of a just-in-time print strategy. With enabling technology in place, we can begin to discuss what a JIT business might look like.

18.3 Just-in-time order processing

The particulars of JIT order processing may differ depending on a number of variables including the product type and business model. No matter the specifics, a number of areas must be addressed for successful implementation to occur, including the capture of order information, management of designs and image data, fabric preparation, printing, and finishing, and order delivery.

18.3.1 Capturing order information

The mechanism for capturing order information will vary tremendously depending on the nature of the business being served by a JIT print model. In many instances JIT printing will involve the manufacture of a sewn product for apparel, home, or accessory item. In this environment, the manufacturer may be responsible for a variety of steps including fabric development, cut and sew, and even the sale of the product to the final consumer. Alternatively, manufacturing may include a variety of supply chain partners, each responsible for a step in the manufacturing process.

Depending on the manufacturing arrangement, the digital printer's 'customer' may refer either to the end consumer or to the retailer/product developer. Whoever the 'customer', it is important to remember that within a JIT strategy, the submission of an order to manufacturing is demand driven. In this 'pull system' the demand for product will ultimately be created by product sales, and these sales may be obtained in a variety of ways including through traditional bricks and mortar retailing, or via catalog and on-line sales. However the product is offered for sale to the consumer, the manufacturer will likely receive just-in-time order information in electronic form in order to speed the process. Order information will outline both quantity and product specifications, including product style, size, print design, and colorway.

In the fashion apparel and accessories markets, retailers are continuously striving to fill their stores and catalogs with new product and fresh seasonal looks. In this setting, product development is constant as design teams work close to delivery and press for shorter manufacturing cycles. The need for quick turns of smaller quantities of new product suggests that product development must coordinate with manufacturing to ensure just-in-time delivery and address any issues that arise during the manufacturing process. Digital printing is well suited to meeting these order demands as it offers tremendous manufacturing flexibility. In addition to quick turns of new product, there may also be a need for ongoing replenishment of basic products or as a result of unanticipated sales of seasonal items. The tracking of product inventory and sales at retail will likely provide the basis for determining these replenishment needs and will trigger order placement.

With respect to online sales, manufacturers may receive their order information directly from the end consumer. Via this setting, consumers may place single or multiple unit orders for standardized product. The e-commerce setting is also well suited to a mass customization business model as it allows customers the opportunity to shop leisurely and view a wide range of products and styles within the privacy of their own home. In this setting it is possible to experiment with a variety of color options, prints, and style features and personalize their products by selecting from lists of customizable features. As 3-D visualization technology advances, consumers will have increasing opportunity to view their customized designs as finished product and even 'try it on' their personal model, in the case of apparel.

JIT is a manufacturing strategy that supports the implementation of both customized and standardized product orders. Keeping in mind the desire to reduce risk at retail and eliminate or reduce fabric inventory at the cut and sew level, digital textile printing is a favorable method for filling both single and multiple unit orders within the JIT setting.

18.3.2 Design and image management

The management of design information is key to the successful implementation of a JIT digital print model. This design information must be ready to print if product is to be delivered in a timely fashion. With this in mind, the strategy for creating prepared-for-print (PFP) designs is somewhat dependent on the nature of the final product and on the specific manufacturing model being served. In general, it is possible to identify two main strategies for image preparation. The first involves the preparation of designs that are color reduced and separated as they would be for the conventional screen print process. These designs are typically created and/or edited using textile-specific software programs. Although the digital print process does not require a color reduced and separated image file, there may be a number of reasons to undertake this process. At the product development level, designers may be working from seasonal palettes that act as a unifying feature or color story within the retail environment. The process of specifying and integrating color from a palette is simplified for an image that is color reduced. Color separated images are also easily recolored and adapted in order to offer multiple colorways, coordinates, and the opportunity for product customization. With respect to production, the digital process may also be used to print short runs of fabric that are introduced into the marketplace as test runs. If the design is popular, it may be worth producing longer runs via screen printing. In this case, the design must be prepared for screen printing and the digital print must be representative of the larger screen print production run.

The second strategy for image preparation involves the creation of designs that will only ever be produced using the digital print method. These designs may be created using textile-specific or off-the-shelf software and may take advantage of the wealth of design possibilities digital printing offers, including photo-realism, sophisticated tonal and textural effects, engineered printing, elimination of repeats, and unlimited image scale. As previously noted, it is even possible to combine surface design information with pattern information for the creation of printed fabric markers.

Whatever the method for image preparation, the design file must be prepared and stored in digital format for the design information to be quickly converted into printed textile within the JIT setting. Once the design is in digital format it can be stored in a library or design archive for easy retrieval. This archive can be used at the product development level for design inspiration and artists can access designs and repurpose them for new lines and seasons. Some businesses may also select to utilize such design libraries as an asset that can be offered to the customer as a customization resource.

18.3.3 Fabric preparation, printing, and finishing

Once the order has been placed and the design has been created, selected, and/or customized, the design file can be placed in a queue for printing. In the JIT environment the digital printer must have access to specially pretreated greige fabrics for specific products and ink types. The breadth of this selection will depend on the manufacturing setup and the nature and range of customers being served. In the fashion apparel market, printers may be required to work closely with product development to identify and cultivate sources for a wide range of PFP fabrics that can be quickly delivered and converted as needed into pretreated goods for digital printing. Alternatively, printers may select to specialize and stock a selection of pretreated fabrics for the range of customers they serve. In either case, the printer must have an effective working relationship with the fabric mill(s) to ensure ready access to raw materials and, depending on the capabilities of the printer, fabric pretreatment may be outsourced or completed in-house.

At this point it makes sense to batch orders for efficiency. The rules for batching orders will depend on the specifics of the printing and finishing setup. For example, some printers may offer printing with multiple ink types on a number of smaller-scale machines. In this instance, orders may be batched by customer and also by ink type and fabric and then sent to corresponding printers. Alternatively, the printer may operate one or more large-scale machines with one or two ink and fabric types. In this case, orders will likely be batched according to customer and fabric in order to minimize fabric changeover.

The requirements for color fixation and wash-off will be driven by the ink chemistry. However the setup will depend on printing capacity and the number and type of printing machines. For example, the printing of short runs of a variety of fabrics using multiple small-scale printers may lend itself to the installation of one or more small-scale, open-width finishing units for production flexibility. In contrast, the printing of longer runs and/or a narrow range of fabric and ink types may lend itself to the use of in-line equipment and/or larger-scale open-width finishing capabilities. Some printers may select to establish finishing in-house, while others may outsource these capabilities. The outsourcing of fabric preparation and finishing may be a particularly attractive option where the digital printer provides other services (e.g. screen engraving or cut and sew operations) and has existing relationships with wet processing mills. Outsourcing of finishing operations may also be an option where applications of specialized chemical or mechanical finishes are required. It is important to keep in mind that JIT is about speed of delivery and so the cost benefit of outsourcing must be carefully analyzed to determine the route that provides the greatest value to all parties including manufacturer, retailer, and final consumer.

18.3.4 Order delivery

Depending on the customer the finished goods may take the form of either digitally printed yardage or digitally printed sewn product. If the printer is responding to an order for digitally printed yard goods, they will deliver this product in roll form to the customer or to another supply chain partner that will cut and assemble the fabric into apparel, drapery, upholstered furniture or other textile product. However, the printer may also be the cut and sew manufacturer. In this case, the fabric will move directly from finishing into cutting. As technology and ink chemistry developments occur, it is plausible that the cutting operation may be placed as an in-line activity to printing. In the case of sublimation printing, it is currently possible to transfer the digitally printed image to cut pieces rather than a roll of fabric.

Once the fabric is printed and cut, the pieces are moved out onto the floor for final product assembly. In order to adapt to quick changes in print, color, and style, sewing operations and other methods involved in assembly may be set up according to modules operated by teams of cross-trained specialists for short-cycle manufacturing. In the case of customized product, the cut parts must be identified as belonging to a single unit and must travel together from cutting through the assembly process. Currently available technology such as the Eton Unit Production System (UPS) can be used to convey and track parts for a single unit through the assembly process. In theory, order number and part identifiers could also be applied during the digital print procedure as another method to ensure that the parts for a custom product remain together. Once the product is assembled, it is ready for packaging and shipment to the retail outlet or final consumer.

18.4 Case studies

The previous sections of this chapter have outlined a vision for just-in-time digital printing. How is the vision implemented in a real-life setting? This section will briefly examine the JIT printing activities of $[TC]^2$'s InkDrop Boutique and the Stork U See digital printing service.

18.4.1 The InkDrop Boutique

The InkDrop Boutique is a small-scale digital textile printing service developed by the not-for-profit corporation $[TC]^2$ to research and demonstrate the capabilities of digital textile printing for the sewn products industry. As of May 2005,

18.6 The InkDrop Boutique digital print area, provided courtesy of [TC]^2.

the InkDrop team makes use of sampling-level digital printing equipment including four printers from Stork, Mimaki and MacDermid Colorspan, along with a batch steamer from Jacquard Products, to produce small quantities of digitally printed sewn product (see Fig. 18.6). They are supported by [TC]^2's team of product development and sewing specialists (see Figs 18.7 and 18.8) who help them to manufacture a selection of customizable products for a range of customers including individual artists, designers, and museum stores.

The goal of the InkDrop Boutique is to utilize their modest manufacturing resources to provide printing on demand and help their customers and visitors to learn about the benefits of digital printing as part of a just-in-time approach to manufacturing. InkDrop currently specializes in reactive dye printing and stocks a small selection of fabrics that are pretreated for that purpose. Their customers provide imagery in digital format, typically as a .tif file saved for the Windows platform. The design area currently uses Adobe PhotoShop as their main product development tool for the integration of imagery into standardized product templates for items including scarves, purses, totes, accessory cases and cushions (see Fig. 18.9). The use of digital product templates that contain cut and sew guidelines simplifies the product development process and helps to enable sample creation and speed to market (see Fig. 18.10).

With respect to production, customers were initially offered minimum order quantities of 10 pieces. However, it eventually became evident that most customers could benefit from even smaller order quantities. With this in mind, minimum order quantities are currently determined in relation to the number of

18.7 Making patterns and cut files for InkDrop Boutique products, provided courtesy of [TC]^2.

18.8 Sewing InkDrop Boutique products, provided courtesy of [TC]^2.

18.9 A sample of InkDrop Boutique products, provided courtesy of [TC]^2.

18.10 InkDrop Boutique design template for tote pockets and purses, provided courtesy of [TC]^2.

pieces that can be printed across a given fabric's width. For most product types, customers can also obtain multiple designs or colorways within a single fabric width. This strategy eliminates fabric waste and customers are able to obtain very small numbers that can be replenished on demand. This environment also makes it possible to experiment with a variety of designs and obtain a selection of unique products with minimal investment in setup time and inventory (see Fig. 18.11).

Repeatability and accuracy of color reproduction is one of the great challenges for digital printing in a production setting. The Inkdrop Boutique uses a selection of color management tools to assist them with this task, including software from Stork, MacDermid Colorspan, DPInnovations, and Ergosoft. They are well versed in the creation of color profiles for specific fabric, ink, and printer combinations and typically create and apply profiles for groups of fabrics depending on similarity of weight and fiber type. Most of the artwork received is full color imagery that can only be replicated via the inkjet environment. They work closely with customers to ensure that color is reproduced according to their specific tolerances. Among their customer base, artists and designers are typically satisfied with a first print approach in which they obtain a printed sample for approval for which there has been no color adjustment on the original file. They have found this to be the quickest and least costly approach for new product development.

Despite the use of color profiles for printing, museums often require greater color accuracy, and in these instances the InkDrop team will use an iterative approach to make color adjustments on the original file to reduce color casts and ensure accurate reproduction. Customers are asked to provide a printed paper version of their image to help guide the color correction process. As this strategy is more costly in terms of fabric, ink, and labor, an additional fee is charged for the service. However, the color-adjusted print file and a printed sample of the color-proofed image is kept for processing replenishment orders. Customer order sheets are used to digitally record manufacturing information related to both printing and product assembly, and the imagery and digital order information are easily retrieved for quick and accurate replenishment on demand.

While most InkDrop customers develop a range of standardized products for their marketplace, some customers utilize the JIT digital print environment to support a mass customization business model. In this instance, product development and manufacturing strategies must be streamlined for successful implementation. The ultimate goal is to develop a 'first print' strategy and to eliminate or minimize color correction and image preparation. From a product development standpoint, the creation of standardized product templates with predetermined interchangeable print features is very helpful. Product developers can maximize the value of their digital assets by creating image libraries and developing design options from archived imagery data. Within this scenario image layout and color reproduction can be predetermined and therefore,

18.11 Example of a printing marker corresponding to fabric width for tote pockets, provided courtesy of [TC]^2.

predicted and controlled to ensure that customers receive the product they envision without color or image adjustments and costly reprints.

In some mass customization scenarios consumers supply the digital imagery to be printed (e.g. a photograph). The InkDrop staff has found this mass customization scenario the most challenging to implement as it is very difficult to control the quality of imagery supplied and to predict and control the color output according to customer and consumer preference. In this situation, they have found it is important to manage expectations and to provide 'guidelines for imagery preparation' and 'tips for best print results' to ease the process. It is also particularly imperative to optimize fabric preparation, printing and finishing conditions and to minimize variables that impact image quality for efficiency and predictability. Through their experiments with mass customization, the InkDrop staff have learned that personalized product can have great value to the final consumer and, although print strategies are not without pitfalls, the InkDrop team will continue to investigate and refine their process.

While their manufacturing capabilities are modest, the InkDrop Boutique service has been of great benefit to their growing customer base that take full advantage of the just-in-time manufacturing flexibility that digital printing enables. It has also been a useful resource for the US sewn products and imaging industries as they investigate digital textile printing and its potential for the creation of unique products and businesses.

18.4.2 Stork U See®

The Stork U See® standardization is an effort to further the adoption of digital textile printing by providing regional service centers for sampling and short-run production that enable color management from design concept through finished product. They currently operate four centers worldwide, with a facility in Thailand that offers production in addition to digital sampling. Stork U See® is described by the vendor as a 'color communication quality standard' and their strategy for printing emphasizes four key areas including software, hardware, consumables and best practices. Stork U See® centers are certified to ensure interchangeability between print machines and locations for consistency of print results.

The facility in Thailand houses a range of printing technology to meet sampling and production demands. As of May 2005, the plant is equipped with 18 printers including 12 Stork Sapphire and six Zircon II machines (see Figs 18.12, 18.13, and 18.14). The facility operates 24 hours per day, seven days per week, and runs two 12-hour shifts in an environmentally controlled building. The manufacturing environment is very clean and offers a comfortable work environment, quite unlike most conventional wet printing facilities that are often warm and humid. The printing area is staffed by six operators who oversee three to six machines during their shift, and Stork is able to offer printing on a range of fabric types including synthetic and natural fiber substrates. Machines are

18.12 Digital textile printing at the Stork U See® center in Thailand, provided courtesy of Stork Digital Imaging.

18.13 Digital textile printing at the Stork U See® center in Thailand – closeup, provided courtesy of Stork Digital Imaging.

18.14 Fabric inspection at Stork U See® center in Thailand, provided courtesy of Stork Digital Imaging.

equipped with closed, bulk ink systems for reliability and efficiency, and Stork is currently building a refrigerated room within the facility to ensure the ink supply is maintained at suitable temperatures. This print environment has been operating at production levels for three years and currently receives orders for runs up to 30,000 yards. In order to meet production demands some of the machines may be set up with more than one ink set for flexibility, while others are arranged with a single colorant type for speed. Open-width steaming equipment from Rimslow is utilized for fixation of samples and larger runs are generally sent to a local facility for post-processing on production-scale equipment.

Stork's proprietary systems for color management are combined with workflow practices to ensure accurate reproduction of color and design according to customer specifications. While the InkDrop Boutique focuses their efforts on serving smaller-scale businesses, Stork has greater production capabilities and their customers include leading European and US fashion and swimwear retailers and product developers. Stork indicates that these customers are able to utilize the digital method to introduce unique product and are also able to reduce the risk of introducing prints into the marketplace through a continuous flow pipeline of JIT product and replenishment on demand.

18.5 Conclusion

In Hall's (1987) discussion of manufacturing excellence, he notes that technological change isn't enough in and of itself. Manufacturing excellence is driven by changes in ' engineering, business, and people' (Hall, 1987, p. 14). In a sense, we must change the way we do business and provide employees with technology, engineering, and training in order to effectively implement a JIT strategy. Hall echoes Wantuck's (1989) belief that a new approach to manufacturing begins with the elimination of waste, the reduction in lead times and cost, and an investment in people, quality, and continuous improvement. The implementation of a digital printing strategy involves attention to each of these factors. The benefits will be evident to those organizations that value innovation in design and production. While implementation of digital printing for just-in-time manufacturing is not without challenge, the rewards may be tremendous. When combined with additional strategies that support short-cycle manufacturing and supply chain management, the benefits may be enhanced for all parties including manufacturer, retailer, and consumer.

18.6 References

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19
Design and workflow in digital inkjet printing

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19.1 Introduction

The history of digital inkjet printing goes back to the nineteenth century, when the English physicist Lord Rayleigh investigated the physics of inkjet technology (Rayleigh, 1878). Beginning in the twentieth century, the first commercial non-impact digital printing started in the 1970s, for the carpet printing industry. In the United States, Milliken's Millitron system, and in Austria, Zimmer's Chromojet system, both became the standard method of modern production. The Millitron system, equipped with 10–20 jets per inch, utilized the computer injection dyeing system, in which the continuous streams of colorants are controlled with deflection by air jets. The Chromojet system is based on the drop-on-demand solenoid valve principle and the computer-controlled valves eject the colorants directly to the substrates. These printers are designed specifically for printing broadloom carpet and tiles, and printing quality is as good as 10–20 mesh of conventional printing technology (Dawson, 2003).

The true commencement of commercial digital textile printing was not actualized until the late 1980s, in which sampling and digital strike-offs were implemented. Although many refinements and improvements in existing printing technology have been seen in the past 20 years (Dawson and Hawkyard, 2000), until recently there have been no large-scale implementations of industrial printing technology. It was not until the 1990s that digital printing technology grew in scope, in terms of applications and price points: from simple consumer desktops, through large formats to industrial applications (Pond, 2000) Since 2000, innovation and growth of new digital printing technologies has led to further implementation in the textile printing industry. Notably, several industrial production digital inkjet printers were introduced at ATME in Greenville, South Carolina, USA, in 2001, and at ITMA in Birmingham, UK, in 2003. At the outset of 2004, more than 100 units of industrial production digital inkjet printers were placed worldwide (Compton, 2004), securing diffusion and replication of emerging industrial expansion. Generally speaking, the evolution of technology is defined as consisting of three stages: (1) invention as discovery,

(2) innovation as the first commercial application, and (3) diffusion as widespread replication and growth (Grubler, 1998). If one considers the integration of digital printing technology in the carpet industry as representative of the innovation stage in the evolution of textile technology, it is about time that industrial expansion occurred.

Digital printing technology has led to new opportunities in emerging textile design styles, which conventional industrial textile printing methods are unable to accomplish. The development of digital textile technology has influenced the workflow of manufactured printed textiles. Digital textile design has generated numerous new image-making possibilities, without the limited numbers of colors, or screen sizes of conventional printing. Digital textile printing expands the concept of design aesthetics by its ability to allow for more creative outcomes in the domain of textile printing. Moreover, this textile technology functions as a new conceptual framework for production and distribution. Changing attitudes have already begun to liberate the textile industry to become more cost-effective from the initial design concept to final distribution.

19.2 Evolution of textile printing workflow

Historically, the manufacture of printed textile design requires a laborious timetable of diverse processes, and specialized professionals, from the creation of the first design to the final stage of production. This system has remained relatively unchanged since the industrial revolution. Today, in contrast, the diffusion of computer technology provides us with convenient access to production information, which ultimately has deconstructed existing paradigms, and in turn has generated new attitudes towards design and industry production. The main principle behind new textile industry production is the term ‘digital’, in which all information processes can be controlled by digital computer technology. Most significantly, two new digital workflows, of digital strike-off printing and full digital textile production, have consequently led to a more streamlined and effective production environment.

19.2.1 Conventional textile printing workflow

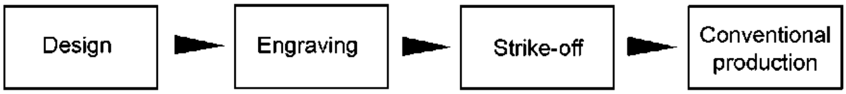
In the current textile printing industry, flatbed screen-printing and rotary screen-printing are the dominant production technologies and share more than 80% of the total printing mechanism. Furthermore, rotary screen-printing accounts for nearly 65% of total printing mechanisms (Stork, 2002). The workflow for these traditional textile-printing technologies consists of several segmented processes. Prior to introduction into the consumer market, final bulk production was developed through the following processes: (1) design concept and development, (2) design modification, and (3) engraving and strike-off.

Firstly, the majority of independent freelance textile designers sell their print designs to textile manufacturers. Although so-called in-house textile designers still exclusively design in manufacturing companies, there has been a shift towards purchasing freelance design work. This is in part due to the fact that companies have more diverse and creative design choices from various freelancers than from their own limited number of in-house designers. It is also due to the fact that existing specialized textile CAD software allows for immediate technical translation of textile designs into standard repeat and color reduction. Although CAD textile software has become an effective technical support system, the majority of textile designs are still created by the traditional hands-on methods on paper. Designers are responsible for visually indicating a limited number of spot colors and repeat sizes in their designs, which are based on these production methods. Once the jobbers, converters, and manufacturers acquire the initial designs, the design modification process begins. By using CAD systems, the designs are inevitably edited and translated into a limited number of spot colors and repeat sizes for a particular printing production method. Production technology determines the pricing and quality of final printed textile products.

After the editing tasks, textile print designs are sent to engravers for creating screens. In engraving and strike-off processes, engravers use CAD systems to separate and convert textile designs into spot color separations. This is one of the most critical processes, in order to maintain the aesthetic integrity of the original designs. In addition to the CAD-operated color separation methods, reputable engravers still depend on manual skills which they have acquired through years of experience. In general, these color separations are stored as CAD data, and translated into separate films, which depict opaque black motifs, that represent each spot color for printing. Traditionally, these films are placed on the surface of screen meshes, which are pre-coated with photosensitive polymers and exposed to UV light, and eventually unexposed areas are washed away. Increasingly, digital printing technology has contributed to the implementation of direct filmless processes.

The separation data from CAD systems applies opaque black ink or molten black wax directly onto the unexposed pre-coated polymer screen surface by inkjet printing to achieve as fine an image quality as 720 to 1019 dpi. After the screens are exposed to UV light, the ink and wax are removed (Moser, 2003; *Int. Dyer*, 1999a). Direct laser engraving technology has also become a viable process, where a carbon dioxide laser beam controlled by a CAD system removes positive images out of pre-coated polymer on the screen surface to achieve more than 2000 dpi. After the engraving process is completed and approved, the printing is executed at the print mill for sampling and proofing. Strike-offs are often sent back and forth between the engravers and design studios for approval.

For the final production, print stylists or design mangers frequently go to the printing mills to approve the final strike-off before the bulk production is



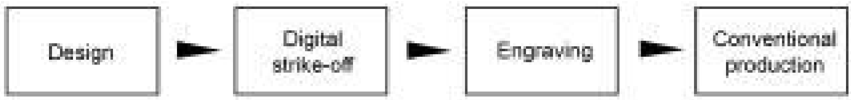
19.1 Conventional textile printing workflow.

executed. Millwork is a lengthy and laborious process for the stylists or design managers, who often work (along with the mill technicians) on 24-hour shifts. This process requires an excellent knowledge of conventional printing methods, including a proficient understanding of matching the color, printing technology, repeat, and eyes to retain the original design aesthetics. This workflow is still the mainstream of the textile industry today and it is highly labor intensive and time-consuming. A thorough knowledge of conventional textile printing technology is instrumental in the qualitative outcome of manufactured cloth. Informed professional design decisions are based on disciplined skills, and more importantly, from well-rounded professional work experience. The workflow is summarized in Fig. 19.1.

19.2.2 Digital textile strike-off printing workflow

A new digital strike-off workflow has been integrated into the conventional printing and marketing process. Instead of using conventional printing techniques to create strike-offs, in which engraving processes are needed, manufacturers have begun to utilize large format digital printers to create digitally printed strike-offs. In this workflow process, manufacturers can use digital strike-offs for market testing and photography shoots, without going through the conventional engraving screen process. Thus, only the marketable designs proceed to be engraved and produced by conventional methods. In contrast, the conventional strike-off process in textile printing can take as long as 6–18 weeks (Spruijt, 1991), with a cost factor of \$90–\$110 for sampling as well as \$260–\$415 per screen creation (*Int. Dyer*, 1999b). In general, approximately only 50% of textile designs that are engraved go into print production yardage (Clark, 2003). By comparison, the digital strike-off workflow process can be reduced to 1–3 weeks and obviously eliminates extra engraving costs, which can sometimes save companies millions of dollars per year (Chapman, 2002). For the most part, this is the most dominant use of digital textile printing today and has continued to gain popularity. It is summarized in Fig. 19.2.

In addition to strike-offs, short-run sample printing has become another popular outcome of digital inkjet printing technology. This is demonstrated in the domestic bedding and fashion industries, which both assemble printed samples for presentation at trade shows. A buyer can more easily be persuaded to come to a decision if dress samples and bedding ensembles are available for viewing. As soon as business is established, and orders are approved, the digital



19.2 Digital textile strike-off printing workflow.

design samples are sent to the engravers and mills for conventional production printing.

The main objective of the digital strike-off workflow is that digitally printed strike-offs should accurately represent the final printing production quality and be producible in conventional printing methods. In order to achieve these goals, computer software plays an important role in analyzing the parameters of engraving information, drop formation, dithering information, and colorant reflectance data of both the digital printer and the color kitchen production environment. Sophisticated software also analyzes complex characterizations of fall-ons and mixes of the conventional textile wet printing process into its algorithm. By implementing color management systems, color accuracy and consistency can be achieved within an input, a monitor, and the printer's output in a designer's CAD station. In this way, textile design can be rapidly altered and quickly respond to the market needs before the final bulk production.

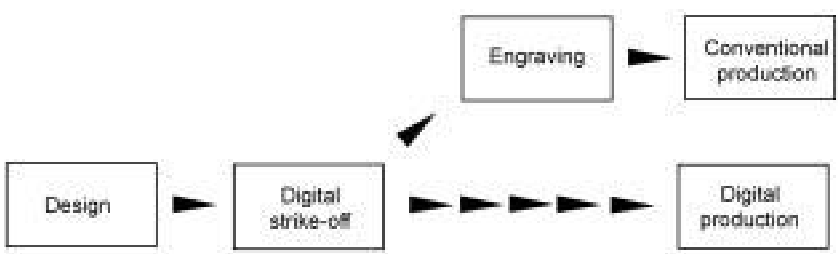
This workflow process is considered most advantageous in locations where strike-off and sampling are on the same premises as designing and editing. Therefore, unlike technicians at mills where conventional printing takes place, designers can function as their own quality control technicians. The designers will be responsible for quick market trends and operating and maintaining their own digital printers in the design studios. Unlike conventional printing, the digital printers do not occupy a lot of space and are environmentally friendly. Digital printers can also be extremely efficient if they are located inside major cities, where the textile design markets are centred. In this way, it becomes highly effective to establish quality communication between printing mills and buyers, instead of at specific remote printing mill sites (Henry, 2004). It is foreseeable that in the near future, once digital production has a lower cost factor and higher printing speed, this printing and marketing process will have wider ramifications in full-scale bulk production.

19.2.3 Full digital textile printing production workflow

ITMA 2003 in Birmingham, UK, has become a benchmark for starting an era of full digital textile printing production. Several robust industrial digital printers were introduced, including the DReAM machine by Reggiani Macchine, the Monna Lisa by Robustelli, the Artistri 2020 by DuPont, the TX-3 by Mimaki, and so on, and these are economically competitive to operate as fast as 150 square meters per hour for printing lengths up to 1000 square meters (Glover, 2004; Moser, 2003). The workflow of full digital textile printing is streamlined without having extra engraving tasks, and all stages of textile design production, from designing, editing and strike-off to production, can be executed under the CAD environment. Information technology includes digital data and asset management as well as electronic communications. It is also adaptable to current market demands of rapid trend cycles and short-run printing lengths with a quick and reliable response. Production quality digital textile printers allow for more original designs in a short to medium run production capacity, which is more economical than conventional printing production. This new workflow system is summarized in Fig. 19.3.

This type of printing process has more flexibility in terms of style and mechanics. A novel design, such as a photographic image or a tonal image, can be articulated without mechanical limitations on the number of color screens or repeat sizes. In addition, the aesthetic image quality of textile designs which are processed through spot color separations in the conventional printing process can be enhanced by the full digital printing production workflow. Instead of translating design to the conventional two-bit raster-based screen separations, each color separation can be printed in the eight-bit tonal separations to retain more precise image integrity. These differ dramatically from the conventional printing methods, and offer a competitive edge for textile printers.

In the current textile printing industry, it is apparent that there is a continuous shift of printing production from North America and Europe to other parts of the world where wages are lower. Asian countries, particularly China, share more than 50% of total printing production worldwide (Stork, 2002). Presently, several printed textile manufacturers in Europe and North America demonstrate full digital textile production workflow for their exclusive high-end fashion and furnishing markets. Integration of full digital textile printing production became one of their survival strategies in terms of differentiation from their peers (Bruni, 2004). On 1 January 2005, the quota system for the textile and clothing sector came to an end. In addition to other sectors of textile and clothing industries, the textile-printing sector will also be more competitive worldwide (Adiga, 2004). Textile printing operations in China are currently considered to be the largest and most successful, and eventually China will become the capital of textile



19.3 Full digital textile printing production workflow.

printing. The future of textile printing in China depends on finding the competitive niche in full digital printing production in order to ensure success.

19.3 New design styles

In general, the assessment of printed textile design production is judged by its commercial viability and original creativity. Commercially successful printed textile designs can be sold continuously for many years. It is not rare for some production yardages to be continuously printed for over 20 years for greater commercial success. On the contrary, favorable value assessments of originality and creativity often result from publicity created by those who affiliate with journals, museums, academia, and publishers (Schoeser, 1986). To a certain degree, many manufacturers fulfill both parameters of good sales and reputable publicity for the success of their business. Although some printed textile designs accommodate both successful sales and well-received PR within one design, most manufacturers prepare two different marketing strategies to deal with these goals. Manufacturers, for example, spend time producing commercially successful textile designs that come from modifications of preconceived traditional textile design trends. These traditional designs are easily modified and processed into production yardage, utilizing previously mentioned digital printing technology. However, time and effort is also spent producing creative and original textile print designs, which are more characteristic of newer 'contemporary' design aesthetics. The success of creative and original designs results from the novelty of the design aesthetic itself, which is largely determined by market trends and textile printing mechanical constraints (Eckert, 1997; Moxey, 1998). The trends of the market in a given time period are established by the symbiosis of political, economic and cultural factors in our society. The designers' inspirations are formed by their intuitions, visual stimuli, and research tasks influenced by a series of the symbiotic social phenomena including demographics, behaviors of consumers, pop culture, media, etc. (Wilson, 2001). Nonetheless, new design styles emerging from digital textile printing are influenced far more directly by the actual printing mechanics.

19.3.1 Textile printing mechanics and design styles

Historically, mechanical methods of textile printing have defined the textile design styles. The history of design styles can refer to developments of the visual interpretation of three-dimensional reality into two-dimensional renderings. To illustrate, beginning more than 2000 years ago, block printing technology was the earliest example of three-dimensional simulation. In block printing, every block represents each color separation, and consists mainly of flat silhouette shapes. A three-dimensional effect of the motif is obtained by printing several separate layers of flat silhouette shapes to create light to dark tonal definitions. The so-called 'traditional floral design style' printed by screen printing technology today still retains the same original look as the historical block-printed designs. Looking back historically, engraved plate and roller printings, which originated in the eighteenth century, evolved into more sophisticated two-dimensional renderings of three-dimensional motifs. These detailed printing techniques represent the finest line and dot quality of historical printed textiles, which are still the goals for today's printing technology. These exceptional effects were rendered with tonal values created by cross-hatching and dry-point techniques, which consist of fine lines and dots. The so-called 'toile design style', which originated from this historical printing method, set the standard for the look of traditional textile designs that are still on the market. In table and flatbed screen-printing technologies, which started at the beginning of the twentieth century, it is rather difficult to achieve perfect motif and screen registration alignment. The perfect butt-fittings of each motif into separate screens are almost impossible to print, especially in the early stages of this technological development.

Eventually, the mechanical limitations of screen-printing began to dictate the print style. Screen-printed designs incorporated different scale motifs and fits, which prevented the problem of mismatching screen registrations. Instead of butt-fitting the motifs, the designers started to create intentional unfitted 'looks' which were built into the design print aesthetic itself. For example, one of the adjacent motifs was either enlarged to have striations of wide trappings or reduced to have striations of unprinted areas. In current textile design, even though the precision of screen registrations has improved, some of the designs still maintain this 'intentional unfitted style' for aesthetic purposes.

In comparison, digital textile printing technology is free from mechanical constraints, which totally differentiates it from any other conventional textile printing processes. First and foremost, the elimination of screens and image transfer media benefits textile designs without step and repeat requirements. Secondly, any design digitally created on a VDU (visual display unit) can become an actuality, directly after it is printed on cloth with the CAD designing software, including proprietary textile design software as well as off-the-shelf Photoshop, Illustrator, etc. Precise color prediction and color matching can be established with color-management software and device calibration tools (spectrophotometers and colorimeters), including input (scanners, digital cameras, etc.), VDU, and output (print-outs). This instant digital imaging process provides textile designers greater opportunities to explore aesthetic novelty and to experiment with new imaging possibilities on fabrics to a greater degree than any previous textile printing technologies.

Although historically there has been initial enthusiasm over new digital technologies, they have had a problematic infancy. When transfer-printing technology was introduced in the late 1960s, the textile printing industry was initially enthusiastic about the potential freedom of image creation without any constraints. There were many experimental explorations of photographic images. However, the industry eventually realized that it was far from liberated, due to the fact that imagery could only be printed on limited synthetic substrates (Stark, 1990). Nonetheless, digital textile printing proved itself to be a technology truly without limitations. With current developments in colorations (inks), digital textile printing has the potential to produce images on almost any kind of fiber, just like conventional printing technology. Consequently, because of its characteristics of flexibility and freedom, digital textile printing technology generates new design styles that are impossible or extremely difficult to achieve by existing conventional printing technologies. Such styles can be categorized as follows:

1. Millions of colors
2. Extreme tonal effects and fine lines
3. Photographic manipulation
4. Special digital effects
5. Large engineered images.

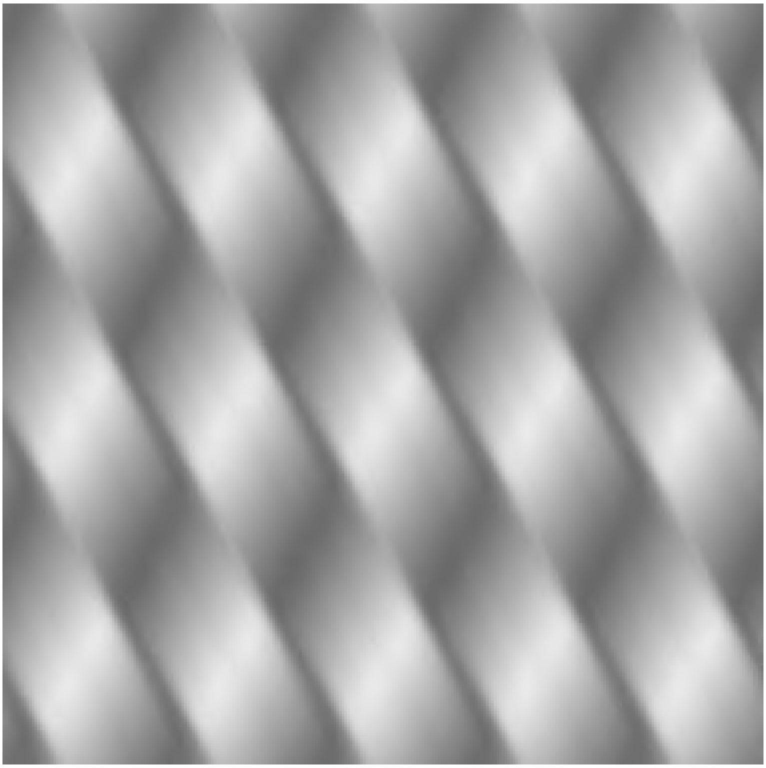
These will be discussed in the following sections.

19.3.2 Millions of colors

Conventional textile printing is based on spot colors which are separately formulated on screens prior to printing. Conversely, digital printing is based on a preset process color of CMYK, whose combinations assign each pixel color of the images of the CAD textile design data. The textile design in CAD software can have the possibility of creation in 24-bit RGB colors. This is one of the advantages of digital textile printing, to visualize millions of colors in designs. Although retainable colors on designs in 24-bit RGB color space hold a much more extensive color gamut than the printable output color gamut, the creative possibilities in this design environment are enormous. Furthermore, several additional process colors become available, which are utilized in conjunction with the existing process colors of CMYK to increase the number of printable colors attainable. Moreover, color management software has been developed to control and manage more than four process colors to give precise color matching and prediction. Currently, in the exclusive high-end fashion printing market, some of the fashion accessories and dress prints use more than 30 colors representing original colorful creative looks. Depending on the volume of printing, these printing manufacturers utilize both digital and conventional printing technologies.

19.3.3 Extreme tonal effects and fine lines

One of the most difficult tasks in conventional printing technology is the reproduction of smooth and clean graduating tonal effects. Throughout the



19.4 Example of extreme tonal effects and fine lines (Hitoshi Ujiie Design © 2000).

history of textile printing technologies, one of the distinctive characteristics of the hand-engraved copperplate and hand-engraved roller printing technologies is the subtle and smooth shaded effects. To achieve these goals, the engravers and printers were renowned for their highly skillful craftsmanship, timeless efforts and experimentation (Storey, 1974). In contrast, digital textile printing has consistent depositions of microliters of colorants, controlled by the dithering algorithm of software, which enables it to produce smooth tonal effects and fine lines effortlessly on textile substrates. Figure 19.4 shows an example of extreme tonal effects achievable by digital printing technology.

19.3.4 Photographic manipulation

Inputs of photographic images through scanners, cameras, and photographic stills from video cameras can be manipulated and printed digitally on cloth. This photographic manipulation incorporates the concept of 'simulation and camouflage'. By integrating the historical idea of the 'trompe l'oeil style', which refers to a design style that creates a 'trick of the eye', printed photographic images can simulate the visual illusion as well. Historically, this ‘trompe l’oeil style’ has been rendered with stylized painting techniques. The ‘simulation and camouflage style’ is defined as the photo-realistic version of the ‘trompe l’oeil style’. The design exhibition ‘Skin: Surface Substance and Design’ at the Cooper-Hewitt National Design Museum in New York in 2002 represented various photographic textile designs that simulated the illusion of real surfaces and/or objects on digitally printed textile substrates. These design images created provocative visual illusions, which generated the notion of unexpected and unusual textile design. The concept of ‘camouflage’ on digitally printed textiles has been explored in military uniforms, developed not only for visual images but also camouflaged from infrared and other sensing devices. An example of photographic manipulation is shown in Fig. 19.5.

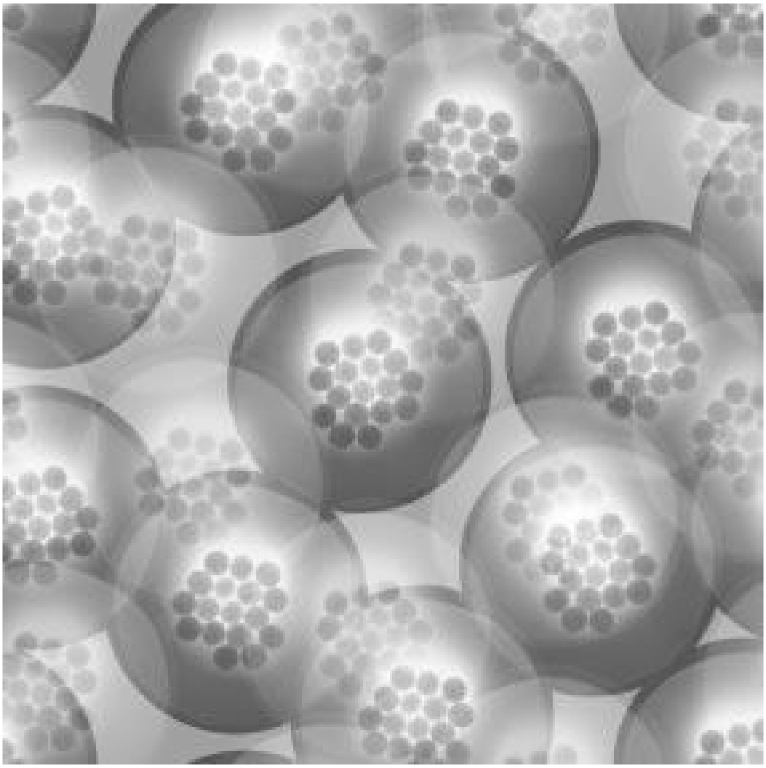
19.5 Example of photographic manipulation (Ion Design © 2000).

19.3.5 Special digital effects

The new printed textile designs can be characterized by a variety of special digital imaging effects. The image editing software provides a variety of digital effects by filtering and distorting tools. Any image can be manipulated to look digitally distorted and sometimes it gives an obviously prefabricated ‘digitally distorted and filtered’ outcome. This could be considered controversial in terms of the authenticity of the originality of the imaging process, if the result represents too generic a digitally distorted and filtered look. Nonetheless, utilizing special image-editing software can be a great creative tool to visualize novel textile designs. Figure 19.6 shows an example.

19.3.6 Large engineered image

A textile designer no longer needs to create images where the size and scale of the motifs are influenced by the mechanical and financial restrictions of the engraving process. Designers no longer need to be concerned with the concept of repeat and they can create one enormous engineered print for interior textile



19.6 Example of special digital effects (Hitoshi Ujiie Design © 2003).

design and fashion design applications. The potential of repeatless imaging in printed textile design is immeasurable. Linking personalization and mass customization to a new business paradigm shift, where any choice of design can be printed on any desirable placement on demand, is the next wave of the future. Additionally, digital textile printing has stimulated the interest of artists, who visualize the images printed on textiles in the same way as paints on canvas. In 2002, the Textile Museum at Washington, DC, sponsored the exhibition 'Technology as Catalyst: Textile Artist on the Cutting Edge', in which half a dozen artists and designers utilized digital printing technology on textiles to represent multiple creative possibilities. The *Washington Post* reviewed the exhibition as an 'enhancement of an art form' as well as showing 'unimagined freedom of scale'. One kind of digitally printed fabric has the potential to be explored as installation pieces, advertisements, stage sets, and art objects that allow for experimentation in the scale of figure to ground. An example of such a large engineered image is shown in Fig. 19.7.

In the printed textile field today, implementation of digital printing technology will allow for a more comprehensive understanding of the textile

19.7 Example of large engineered image (Hitoshi Ujiie Design © 2001).

design process. Digital literacy is mandatory for successful competition in the current textile market, whether for individual entrepreneurial success, or for industry standards. At the same time, this instant printing technology has created the opportunity for any digitally literate person to produce printed production, whether or not it is aesthetically qualitative or commercially viable. The role of textile design becomes a major part of the successful manufacture of printed textiles.

19.4 New definitions for the textile printing industry

In general, the introduction of new technology influences society and changes our global structures and value systems. The classical industrial revolution in the eighteenth and nineteenth centuries introduced new machinery, labor systems and management styles in manufacturing. At the same time, it shifted socio-cultural values, attitudes and lifestyles (Kranzberg, 1989). Diffusion of information technology in past decades also attests to the fact that many social and economic impacts were reflected in our society. Similarly, the evolution of digital textile printing technology has imposed new historical definitions and systems related to printed textile production and distribution.

19.4.1 On-demand production

One advantage of digital textile printing is the digital management system, where the manufacturing and distribution processes are controlled and managed digitally. With the use of information technology, manufacturers communicate with individual consumers through the Internet and customers' printing needs are met immediately. Unlike the conventional textile printing environments, which require sizable inventory of screens, variety of colorants, and printed productions, by comparison digital manufacturing minimizes the inventory to digital information storage media. Manufacturers can also actualize the concept of just-in-time manufacturing by managing and synchronizing all stages of digital information. In the just-in-time digital textile printing manufacturing system, manufacturers can demonstrate one-to-one marketing to customers with electronic commerce, and the consumer's unlimited choices can be printed as personalized textile products. Moreover, digital manufacturing can link mass customization to a larger consumer domain. Manufacturers prepare a series of choices for design elements of the products through electronic commerce. According to the customer's choice of design elements, manufacturers can produce on demand. In conventional mass production, manufacturers provide tangible products from which consumers purchase. However, mass customization is the interactive exchange between the manufacturer and the consumer in the mass-market domain. Significantly, the focus has shifted individual customer's needs and preferences (King, 2002).

Seiren Viscotec in Japan provides one of the earliest examples of mass customization. On their website, the customer first determines his or her image selection method from two choices: (1) downloading the design software online to create the customer's own images on their personal computer, or (2) selection from prefabricated design elements and colors. Secondly, the customer chooses background colors and types for high quality T-shirts, where the images are placed. Finally, the digitally printed products ordered by the customer are delivered within two weeks. In both personalized and mass-customized manufacturing systems, digitally printed textile products can be categorized as value-added products, which is one of the characteristics of digital textile printing today.

Historically, the acceptance of new technology depends on end-users' psychological acceptance and readiness. The so-called 'Generation Y', an upcoming consumer group, is one of the largest consumer groups in the USA. Its members, who were born between 1979 and 1994, possess the highest digital literacy and value products in which qualitative form and function appear to be components of successful marketing and key to the success of new manufacturing styles (Neuborne, 1999). Moreover, the success of these new manufacturing styles is attributed to the assurance and reliability of the interface and management in production, distribution and communication systems.

19.4.2 Cross-disciplinary application

Currently, total annual worldwide textile print production has reached over 18.6 billion linear meters, and is increasing 1% a year (Stork, 2002). This figure represents all conventional printed textile production in the areas of clothing, decorative interior textiles and technical textiles. Aside from the textile industry, the graphic printing industry also utilizes textiles as printing substrates for their advertisements for printed products such as soft signage, pop materials, trade show graphics, flags, banners, etc. According to Web Consulting, digital printing technology has penetrated far more in the graphic design industry than in the conventional textile industry, in terms of digitally printed images on textile substrates. This is just one of the opportunities for the success of cross-disciplinary applications with new digital printing technologies. The use of the printing technology in a specific industry can be explored in diverse industries to maximize the creative possibilities. A digital textile printer can print images on different material surfaces with proper specifications of colorants and pre-treatments, without requiring much downtime for changing the different colorations. This technology retains various cross-disciplinary opportunities, including researching more universal applications of specific types of printing colorants. Studies on the subject of 'universal sets of colorations on digital textile printing', could possibly lead to novel engineering that enables us to print with one universal set of colorations for a variety of substrates. The same textile design could presumably be actualized on various substrates of metal, ceramics, wood, plastics, etc., without changing types of colorants, and consequently increase opportunities for cross-disciplinary printing platforms.

The cross-disciplinary approach is also manifested in the new business concept of 'vast customization'. This term was introduced by I.T. Strategies in 2002. It defines the new business model as mass customization of a variety of products with digital printing technology. For example, printed products in the home furnishing market can be digitally printed, and mass customized, to create a visually cohesive interior. Such products can include bath rugs, comforters, mattress pads, shower curtains, towels, bed spreads, pillows, window treatments, sheets, table tops, etc.

Furthermore, this cross-disciplinary approach has influenced the creative attitudes of various textile design communities. As textile designers broaden their preconceptions of textile design, they have the ability to create more cross-disciplinary environments with digital printing technology. Collaboration between architects, fashion designers, and graphic designers is already in the preliminary stages of fruition, due to innovative digital printing capacities. To illustrate, a textile designer could easily collaborate with an architect by creating an installation of printed fabric into an entrance of a specific building. Ultimately, the definition of textile design will be broadened into a larger category of surface design. Digital technology will allow surface designers to print virtually any image on any type of substrate surface. For this reason, textile/surface design will most likely integrate more experimentation between the tactile surface and the printed image. A more innovative exploration between surface and print elements will introduce a 'new' look in textile design. In the future, the creative possibilities will be endless.

19.4.3 Entrepreneurship

Initially, during the development of digital textile printing technology in the past decade, the marketplace was filled with positive and enthusiastic attitudes towards this new technology. The printer manufacturers, software companies, and ink suppliers were promoting their products to the textile industry, and in turn, the textile manufacturers were interested in learning about the digital printing systems. In the early days of development, the majority of digital printers and software were designed for the graphics industry. These were modified for the textile industry and were originally engineered solely for textile printing production. At the same time, the equipment manufacturers, OEM companies and suppliers had very limited understanding of the textile industry. Naturally, there was much confusion generated in the marketplace, which delayed the penetration of digital printing technology into the textile printing industry. During this period, textile machine manufacturers developed complete digital textile printing systems. However, the system and equipment costs, as well as the conservative attitudes of the textile printing manufacturers, at least in the USA, created widespread reluctance to accept this new technology. Therefore, the early pioneers of digital textile printing were not the conventional textile manufacturers, but rather specialized or smaller entrepreneurial groups such as a printer for automobiles in Japan, silk printers in Italy, design companies, graphical service bureaus, system integrators, etc. (Tippett, 2001). This entrepreneurship is still the backbone in the development of digital textile printing today.

As previously mentioned, the ability of short-run production with digital textile printing technology is encouraging textile designers. Today they have the opportunity to demonstrate viable personal work, which is digitally printed on fabric, to prospective clients. A new breed of independent entrepreneurs with access to digital printers will be able to produce their own limited yardage. Individual designers can create their own short-run printed textile collections unlike in traditional printing, which requires long print runs and high engraving costs. In New York City, entrepreneurial designers from around the world exhibit their textile design products in the ICFF (International Contemporary Furniture Fair). Year by year, increasing numbers of textile designers present original short-run digitally printed textile products. In the near future, the textile printing industry will become a new form of 'cottage industry', with a few large printing mills and many small printing operations supported by entrepreneurship.

19.4.4 Pedagogy and industry

Interaction between the global expansion of the digital textile printing industry and educational institutions is critical for the worldwide success of this new market. The new skilled and creative talents from educational institutions eventually become the next workforce. At the same time, educational institutions are responsible for placing their students in their specialized professional fields. This demand and supply mechanism of the industry and educational institutions helps to proliferate the entire field.

The introduction of any new technology and principle requires pedagogic revision in educational institutions. Recent developments in digital textile printing and subsequent pedagogic revisions in textile education include textile engineering, science, management and design, but the most outstanding revision has occurred in the area of textile design. The introduction of new digital printing technology has expanded the design processes and the designer's roles, which previously had been separated from the production process. The new skilled textile designers of the future will be required to have more direct involvement from start to finish in the manufacturing process. For example, as mentioned in the digital textile strike-off printing workflow, textile designers are responsible for quality control of printed design, printing process, operation and maintenance of printers, as well as design aesthetics. At the same time, many textile designers will be more involved with the short- to medium-run productions of their designs in the near future. Therefore, future textile design curricula should require technical and engineering components of digital imaging and digital textile printing as well as existing design aesthetics and marketing (Ujiie, 2002).

19.5 Future trends

The first 10 years of our new millennium can be a pivotal decade for innovation in the textile printing industry. In the future, digital textile printing technology will establish its permanent position in the print textile industry. However, because technology is still evolving in the full range of mass-production printing technology, many issues still remain: printing reliability, printing speed, cost of machines and supplies, attainable color gamut, penetration of colorants to the substrates, fastness, etc.

Moreover, digital textile printing is still at the direct printing stage, and special printing application styles can be considered within digital textile printing technology. However, the special printing styles that have been explored thus far have been applied only to conventional textiles. Specialty prints have increased the competitive edge in the textile industry, due to their attractive novelty in the marketplace (Dawson and Hawkyard, 2000). Burn-out, discharge, or any other novel printing style, when adapted to digital printing technology, will generate additional competitive edge to the global textile printing industry.

In terms of further research sources, information can be found in the list of references. There are very few published books specifically on digital textile printing, because the technology is still evolving. The majority of the information can be found in journals and from attending conferences. The journals include the *Journal of the Society of Dyers and Colourists, AATCC Reviews*, *International Dyer*, and the IS&T (The Society for Imaging Science and Technology) journals. The conferences include the NIP (Non Impact Printing) Conference of the IS&T, the Digital Textile Printing Conference of Web Consulting, the Digital Printing of Textile Conference of the IMI (Information Management Institute), the NTC conference (National Textile Center) or its website: www.ntcresearch.org, and conferences and workshops at the Center for Excellence of Digital Inkjet Printing of Textiles at Philadelphia University.

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