Mass Customisation of Interior Textiles via Digital Printing

Dissemination Report
January 2004

Mass Customisation of Interior Textiles via Digital Printing

This report documents the work undertaken by three Rochdale companies, Acton & Acton Ltd, Direct Textile Imaging Ltd., and J. Clegg & Bros. Ltd., in collaboration with Manchester Metropolitan University. This 18-month project (August 2002 - January 2004) received a grant of 50% of the total cost of £167,000 from the Department of Trade and Industry (DTI Project Ref: KBBB/C/012/00134). The partners would like to express their gratitude to the Department of Trade and Industry for its generous support.

Thirteen major milestones were identified at the outset and this report documents the achievements of the project team.

The three companies came together following research into the Rochdale textile and clothing sectors which was carried out in 2001 for the then Business Link Rochdale by Manchester Metropolitan University. This research looked at ways in which the sector could be strengthened. Upon reviewing the research findings, it became apparent that 3 companies had, between them, the core skills for developing a mass-customisation route for interior textiles.

- **Acton & Acton** had an existing business manufacturing mainly bedding products for individual consumers, via a distribution network of UK shops. The dimensions of the products were chosen by the customer, and fabrics were selected from a range of options (mainly plain colours, with a few prints).
- **Direct Textile Imaging** was developing as a sampling and photoshoot business, but looking for ways of developing digital printing technologies to operate in new markets.
- **J. Clegg & Bros** was already offering a transfer printing service and had received a DTI SMART development grant to explore different ways of preparing fabrics for digital printing.
- **Manchester Metropolitan University**, through an ERDF project delivering services to the NW England textiles cluster of companies, was already supporting small projects involving the digital printing of textiles, and was actively seeking to extend this work.

An outline proposal was submitted to the DTI in September 2001 and shortly afterwards the team met with a representative of the Consumer Goods and Services Directorate to discuss the idea in more detail. This led to a full proposal being submitted in the Spring of 2002 and approval for the project was received in July 2002. Since then, regular monthly meetings have been held to monitor progress, chaired by Stephen Kay, the Textiles Business Adviser of Business Link North Manchester, who has also acted as project manager for the project.

Executive Summary

The main aims of the project were to:

- Improve colour management procedures
- Develop methods for the three companies to work together
- Produce and continually refine a range of trial products
- Conduct some market analysis of these products
- Support this initiative with an exploration of product costs

During the 18 months of the project, substantial progress has been made in developing the mass-customised route. The three companies have been stimulated by technology developments, new product ideas and have been opening up opportunities for bringing innovative products to consumers. All the original objectives have been achieved.

A specific route (sublimation dye) for bringing polyester products to market has been proved, and the foundation has been laid for ensuring reliable colour management. Products have been tested against acknowledged industry standards of colour fastness and this has confirmed that their performance is comparable to fabrics printed using more conventional routes. At the time of writing, further trials are underway with certain shades, using a UV inhibitor to further improve light fastness.

The three companies are now able to operate as a virtual company, with information systems that all can access and update. They have formed a new company "Virtual Gallery" to develop their presence in the marketplace, supported by a web site and promotional material.

Cost modelling has revealed a major difference between sampling/photoshoot businesses and mass-customisation businesses. A greater awareness of the cost base provides a much clearer framework for thinking strategically about future development of the business. The largest individual contribution to cost emerging from this work is the business overhead.

Experiences with customers and potential customers have revealed that a major concept shift has to take place moving from traditional supply of made-up products to mass customisation. The challenge of developing new markets has meant that the supply chain should be as short as possible.

The design potential of digital printing of textiles is only beginning to be explored. Consumers are generally not yet aware that products from the digital route can have unique design features and are more environmentally friendly than conventionally printed textiles. Although there is still much work to be done, this project has helped to move the technology closer to the customer.

The Project Partners

Paul Noone (Direct Textile Imaging Ltd.) and
David Acton (Acton & Acton Ltd.)

John Clegg
(J. Clegg & Bros. (Rakewood) Ltd.

Steve Kay (Business Link North Manchester)

David Tyler (NW Advanced Apparel
Systems Centre, Manchester
Metropolitan University)

Profiles of the project partners

Paul Noone has an honours degree in textile technology and management from UMIST and can call upon 15 years of experience in the industry. He joined Colplan Engineering in 1996 and was instrumental in setting up The Direct Textile Imaging Company as a subsidiary of Colplan in 1999. The company provides a digital sampling service to many of the high street retailers and has enjoyed consistent growth by meeting the increasing demands of its many customers.

John Clegg's family has been in the textile industry for around two hundred years. Based in a conservation area at Rakewood Mill, Littleborough, John has overseen the company's transition from a traditional textile finishing plant (with its attendant effluent problems) to much 'greener' working methods. Digital Printing technology fits neatly into this strategy.

David Acton has spent 46 years in fabric development/marketing, working for English Sewing Cotton, Tootals, Viyella and Dewhirsts on industrial apparel and interior textiles. He now manages his own business supplying customized interior textiles and is currently enjoying the cutting edge of digital printing and pursuing textiles' "final frontier", that is, fabric on walls.

Steve Kay has been in the textile industry for most of his working life, starting as a management trainee with Smith & Nephew and progressing to senior fabric technologist for Coats Viyella in the UK and Morocco. He joined the then Business Link Rochdale in 1999 and has since managed a number of textile sector projects.

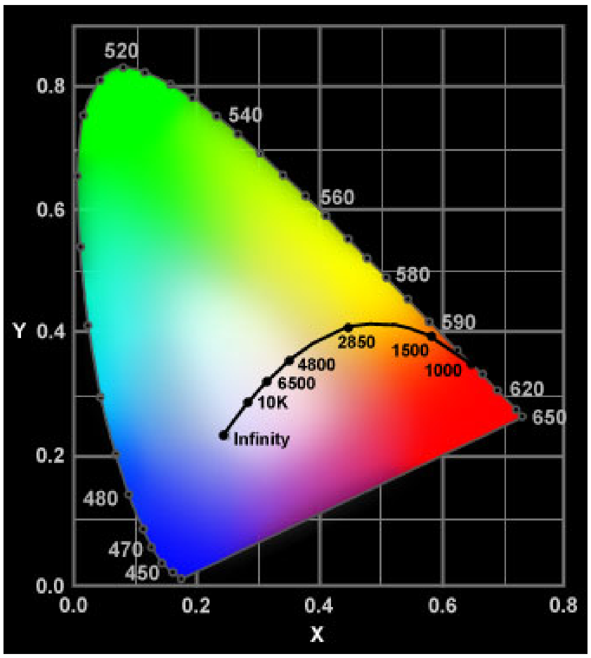
David Tyler has a background in the physical sciences and his involvement with the apparel industry began by analysing industrial problems from a physicist's perspective (Hatra, Nottingham). This led to employment within the industry, initially as a technologist and then as a manager (Courtaulds Ltd.). After joining the Department of Clothing Design and Technology at Manchester Metropolitan University, he has pursued a number of research interests related to responsive manufacturing, systems modelling and new product development. Since March 2000, he has managed the North West Advanced Apparel Systems Centre, a European-funded initiative to support clothing, textile and footwear companies in NW England.

Contents: Project Tasks and Appendices

Task 1: DEVELOP TRICHROMATIC COLOUR SPACES

The problem seen at the start of the project was that much of the then current CAD 'colour space' was unusable, as black was often added, resulting in dull, 'pixellated' colours. This milestone aimed to develop the maximum possible usable colour space suitable for the intended end uses.

The CIE standards go back to1931. They are intended to model the vision sensitivity of a human observer. The main advantage is that the colour produced by one set of primaries can be matched to the colour produced by another set of primaries by adjusting them to produce the same CIE coordinates.

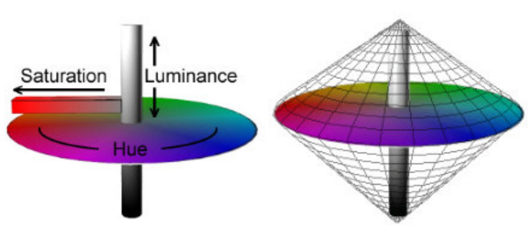


CIE space is represented by an x-y plot with green, blue and red primaries occupying different limits of the colour space. Moving around the boundary allows a change of ***hue***: moving anticlockwise goes through the spectrum: red, orange, yellow, green, blue, indigo, violet. In the illustration, numbered locations along the curve are the wavelengths (in nanometers) of the colours. The filled area represents the space of colours that can be perceived by the human eye.

As one moves from the outside margin to the centre, there is a dulling of the colour: the hue becomes less saturated.

Also indicated on this plot is the spectrum of a black body emitter at defined temperatures. The sun has a surface temperature of 6000K and so daylight is approximately at the heart of the CIE space.

The third axis for this colour space extends the space to define ***intensity***, the lightness or darkness of the colour. This is illustrated below.

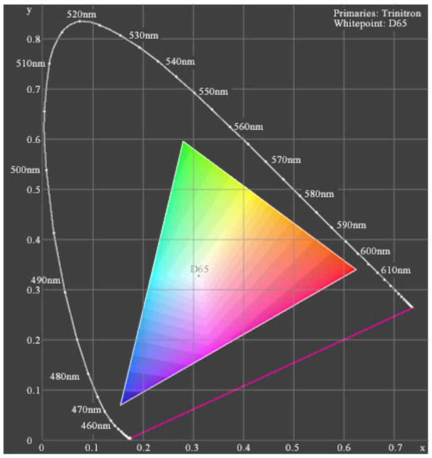


The upper point of colour space is white and the lowest point is black.

By specifying hue, saturation and luminance, the total range of theoretical colours can be defined.

Summary of this terminology follows:
Hue gives the colour of the spectrum (e.g., red, green, purple, yellow)
Saturation is a measure of depth of colour, for example: vivid pure colours versus pastel colors (e.g., red is highly saturated, pink is relatively unsaturated)
Lightness or Brightness is the perceived intensity. Lightness is used for reflecting objects whereas brightness is used for light-emitting objects (light bulb, sun, computer screen).

Printers, CAD screens and other tools for communicating colour are not able to reproduce all the theoretical colours. For each, a colour gamut must be defined. This colour gamut informs the user of the colours that are within the capability of the printer, CAD screen, etc.



This plot shows the theoretical curve and the practical colour gamut of a computer monitor. The monitor generates colour using phosphors that emit red, green or blue light radiation.

As monitors age, the gamut changes. Different manufacturers will produce monitors with different gamuts. Clearly, any attempt to standardise will require calibrating the monitors. A similar situation applies to printers.

Before the project commenced, Direct Textile Imaging had very limited options for controlling colour. As a bureau, the customer chose the colour scheme for a given design. Some used Pantone shades and others provided existing prints. Direct Textile Imaging would work with the customer specification and make an initial “best effort” to achieve that colour in a printed sample. This was followed by visual inspection and, if the match was not good enough, would make a “best guess” as to how to correct the mismatch. Sometimes this would be a quick procedure; at other times it would take hours!

The next approach to overcoming the problem was to use colour books. This was a facility offered by Sophis (the market leading software supplier used by Direct Textile Imaging). This allowed 42 pages of colours to be printed out, each representing a slice of the CIE colour space. In principle, this allowed 32,000 options to be explored, but many of these options would be outside the colour gamut of the printer, many turn out to be the same saturation, some are pixellated and some have a large amount of black in them resulting in an unacceptable appearance. Subjective judgments needed to be made about which options within the gamut were commercial. So, although there were problems, this route did provide a way forward.

A further problem is that Pantone colours, typically used as a reference standard, are inherently inaccurate. Different Pantone books vary, and there are changes with an individual book with time and with humidity. The only way to control colour is through spectral values - the Pantone colours can only be regarded as a guide to what particular spectral values will look like. Designers and Buyers are not used to working with spectral values and this creates a further source of variability for the digital printer.

The original plan for the project was to expand the range of shades available through the colour book approach. Instead of using black (which is acceptable for paper printing but not for textiles), the plan was to develop the colour space by a careful choice of the other dyestuffs being used. The objective was to create a new colour book with saleable colours, linked to pantone standards wherever possible. Acton & Acton would then offer customers specific colours and would get them to select from the range (*i.e.* they would agree that the colour for their corporate logo was, for example, colour G78).

With the machinery available, Direct Textile Imaging could work with either 7 or 8 dye colours. By avoiding black, it would still be possible to move around the colour space, but the resultant colours would be pure and aesthetically pleasing. Black dye was to be used to generate a separate page of the colour book going through a range of greys to black. The eight colours selected were: Black, Royal blue, Mid green blue, Turquoise, Cherry red, Blue red, Orange and Yellow. Initially, every combination of pairs of colours was selected. So, for example, take Turquoise and Lemon Yellow. This was used to create a smooth transition from Turquoise to Lemon yellow, maintaining the saturation and then reducing the saturation to achieve very pastel shades.

This work was very time-consuming but it did lead to useful colour books. The pale Pantone colours showed the need for more attention to the light shades. With some deep shades, it was found that applying more dye achieved no change in saturation: a finding with implications for managing dye usage.

With these colour books, supplied to all three companies in the project, colour communication was effective and could be managed. This has been a successful outcome of the project.

However, the work coming through from Acton & Acton has not majored on solid colours. Seeking to exploit the potential of digital printing, much of the work has involved images. The colour book approach does not help much in the management of colours in graphic images.

The AVA system and system calibration

During the course of the project, it became apparent that the Sophis software system was losing its place as a market leader, and a Macclesfield company called AVA was fast developing as a new leader. A link to this company is via http://www.avacadcam.com/

The AVA software was capable of managing colour to link sample, monitor display, paper printing and textile printing. This is done by extensive calibration of components and software routines that ensure the whole system is coordinated.

The procedure is as follows:

- A setup routine uses a specified mix of dyes with known spectral data
- A substrate is printed with a range of standards
- Spectral data of the prints is obtained and compared with the dyestuff database
- Revised specifications of mix are calculated so that the intended print spectral data is obtained.

Within the AVA system, calibration is also extended to the screen display (RGB colour) and the paper printer (CMYK).

Within the AVA system, a whole image can either be processed as a scanfile or parts of it can be isolated and edited using colour separation techniques. As an example, a flag could be isolated so that the corporate colours could be applied. The system will alert the user if the colours go outside the colour gamut of screen or print.

Task 2: ESTABLISH COPYRIGHT IMPLICATIONS

A key challenge for the project partners has been to accurately reproduce a wide variety of designs supplied by customers. It may well be that copyrights exists on some of these designs, and the project sought to evaluate the implications and establish a best practice approach to such issues.

Copyright is a right granted to creators under law. Copyright in all artistic works is established from the moment of creation - the only qualification required is that the work must be original and there must be evidence of who created the work and when it was created. There is no registration system in the UK; copyright comes into operation automatically and lasts for the lifetime of the creator plus a period of 70 years from the end of the year in which he or she died. After the death of the artist, copyright in his or her works is usually transferred to the artist's "heirs" or beneficiaries, who then become the copyright owners. When the 70-year period has expired, the work enters what is called the "public domain" and no longer benefits from copyright protection.

The copyright owner has the exclusive right to authorise the reproduction (or copy) of a work in any medium by any other party. This includes storing a work in electronic form. Any reproduction can only take place with the artist's consent. Permission is usually granted in return for a fee, which enables the artist to derive some income from the use of his or her work by others.

If an artist is commissioned to produce a work, he or she will usually retain the copyright unless an agreement is signed which specifically assigns the copyright. When artists are employees and create work during the course of their employment, the employer retains the copyright in those works. The current legislation which covers copyright in the UK is the Copyright, Designs and Patents Act 1988, as amended 1st February 2002.

Consequently, as a working practice for this project, the copyright status of all images used in the digital printing of textiles must be established by the customer, and authority to use the images must be documented prior to a contract being signed.

Task 3: DETERMINE IT REQUIREMENTS/PURCHASE EQUIPMENT

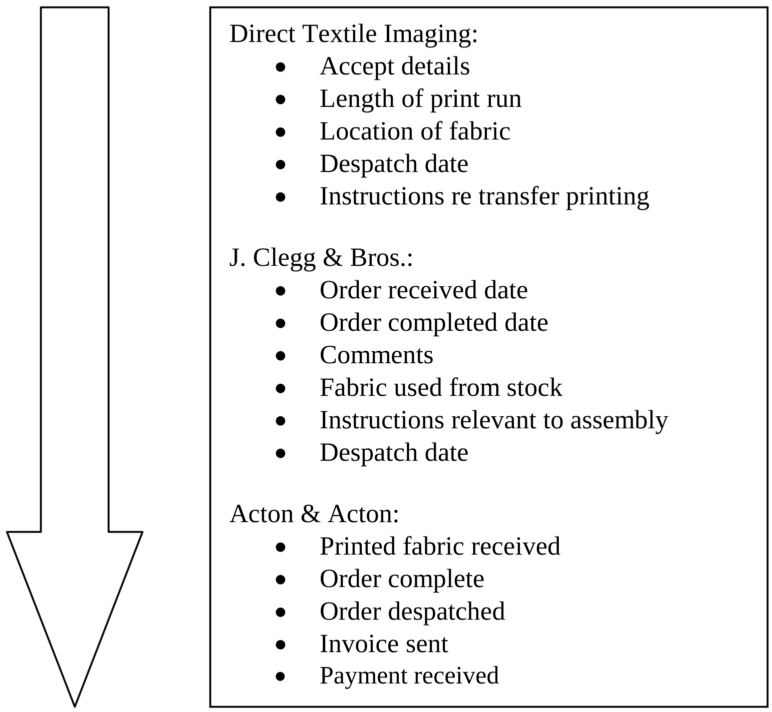
The project partners envisaged order receipt, documentation and tracking to be performed online. There was a perceived need to share work in progress information from all three companies to ensure that the high degree of flexibility and quick response intended from this supply chain is achieved.

The investment needed was predominantly software, not hardware as originally anticipated. The software has been customised to the specific requirements of the project. This followed an extensive audit of requirements. The Menu screen reads as follows:

1. Message Board
2. Order Form
3. Orders in Work
4. Compiled Orders

5. Libraries: fabric types & prices, designs, graphics and photographs.

1. Message Board. Inter-company chat, comments, memos, all dated.
2. Order Form: available for completion by any of the three companies. Boxes for date, time, product type (bed linen, pictures, blinds, etc), sizes, number of items required, fabric type, etc. There are boxes for completion by each of the three companies detailing their particular responsibilities. One of these boxes addresses the issue of copyright clearance.
3. Orders in Work. These are viewed by all three companies. The flow chart is as follows:



Flow chart to show how the three companies integrate their activities

The Compiled Orders and the Libraries are essentially archived data and resources that can be accessed at any time.

Whilst the project partners do not make any claims about the originality of this approach from the perspective of information technology, it is considered to be a major step forward for the three companies, two of which have had very little experience of email and intranet applications prior to the project. In our experience, the number of SMEs trading with comparable information systems is very low.

Task 4: ESTABLISH PROVISIONAL SPECIFICATIONS FOR TRIAL RUNS

Product specifications, in terms of performance and manufacture, may differ slightly from conventionally printed interior textiles. This aspect of the project drew up initial specifications based on current market requirements and process capabilities.

(a) INITIAL STAGE

At a very early stage potential end uses for digitally printed interior textiles were established - the end uses were instrumental in deciding the types of trial runs the companies would originate.

(b) PRODUCT SELECTION

The products selected for the investigation had relatively high square meterage. Duvet covers were chosen for its potential to reproduce unique images, and also for the potential to complete a matching set. Roller blinds and wall hangings were chosen because of the opportunity to put striking images on the product. Large pictures were of particular interest because of their potential to transform the appearance of a room and because of the high value-added.

(c) OPTIMUM UTILISATION

In order to achieve optimum utilisation of early trials we took into account our later requirements for a customer workshop & brochures - which is why the images and base fabrics were chosen with great care and deliberation.

(d) TECHNICAL REQUIREMENTS

Technical requirements of the finished products were also identified – light fastness, wash performance, abrasion resistance, rub fastness, weight and texture of the fabric, resistance to alkaline perspiration, availability and cost.

Product	**Lightfastness**	**Washfastness**	**Abrasion resistance**	**Rub fastness**
Duvet covers	✓	✓	✓	✓
Curtains	✓	✓		
Blinds	✓			
Wall-hangings	✓			
Towels	✓	✓	✓	✓
Pet mats	✓	✓	✓	
Furnishings	✓	✓	✓	✓

Task 5: PROCESS TRIAL RUNS

Initial processing of trial runs was designed to enable the project team to assess the technical shortfalls of the technology in question, and thereby determine the improvements necessary for the technology to make the transformation from a sampling tool into one capable of manufacturing product.

The first period of work involved J. Clegg & Bros. printing out numerous trial swatches to achieve the correct colour yields required from the original design, after being put into the CAD software, manipulated, printed onto paper and transferred across onto the fabric. Apart from drift between monitors, scanners, etc., dispersed inks printed onto paper yields a different colour to that achieved when both transferring and fixation occurs.

Consequently, the system adopted had to anticipate these changes and generate the colour that would be developed after printing and transferring at 200ºC. The end result must match with a colour shade input from, say, a scanner working with a paper document. A successful software system has to remove drift for it is this which gives some images an overall blue or yellow or red effect, as one colour permeates the others.

J. Clegg & Bros. supplied fabric samples and a wide range of fabric surfaces were examined to establish ideal base fabrics for the project. This work carried into the second period and incorporated trial runs.

The inkjet paper used became a concern. Thin paper could not carry heavy ink loads and cockled badly on drying. The consequence was that creases formed during transfer and this produced white streaks on the print. In addition, there were also problems with colour “marking off” on the reverse of the roll. A thicker quality paper performed better, holding the heavy ink quantities needed for dark shades, but it was found that it did not release all its’ colour on transferring until the temperature reached 200ºC at 30 seconds. Consequently, new process values had to be introduced as, clearly, some effect on handle and light fabric distortion may occur at these process temperatures.

Correct setting of the fabric prior to transferring was identified as an essential prerequisite of the process, in order to achieve dimensional stability. Thus, it is not feasible to transfer an image onto any available length of polyester fabric. For example, Lycra/polyester mixes, other stretch fabrics, crepes, voiles cannot easily be processed at these high temperatures.

Periods three and four encompassed more trials with more materials. The trials involved panels printed instead of full colour prints.

Task 6: ESTABLISH COST INFORMATION FOR TRIAL RUNS

By the end of the trial run phase, a large amount of costing information was gathered. This was then collated into an indicative cost model.

In the most basic terms, a cost model is a method for evaluating cost of a sequence of processes. A collection of cost structures is brought together to form the cost model. Cost structures are made up of cost types, cost parameters and cost functions. A cost model is an economic model for estimating the development and/or production costs of an activity or product.

The reasons for using cost modelling techniques in this project are mainly due to the fact that textile digital printing is an emerging technology. There is an increased interest in the concept of mass customisation, which is the area that the three collaborating companies are involved in. Also this project involves three different companies working in partnership so cost-modelling techniques were used to aid the inter-dependent business partnerships. Finally, as digital printing onto textiles is a new and emerging industry a new business model would therefore need to be developed.

Due to this new technology it is inevitable that there is very little or no historical data from which to learn about the process and to relate to the system costs. Digital printing is still in its early stages and still in the transition from being a sampling tool to a production tool. Any previous history of digital printing must therefore be drawn from sampling which is not necessarily relevant for determining the costs of digital printing as a production tool.

A suitable method of cost analysis is therefore necessary in order to determine a cost breakdown of the production process, which at the same time will highlight areas which may need specific attention to enable the digital printing production process to operate economically.

It was decided that the final cost model would depict an activity based costing of the actual digital printing process with the addition of the costs of transfer printing. A separate model was made to determine the cost of transfer printing and the cost was then included in the final cost model. For pragmatic reasons, the final model did not include the actual cost of the cut and sew of product make up.

The reason for not including the costs of cut and sew in the final cost model was because new technology was not being used in this process and an analysis was not necessary. All the pricing structure was already firmly established. The only change to be made in pricing a finished product would be the cost of the digitally printed fabric which emerges from the final cost model.

Identifying the cost parameters.

The parameters are any factors that influence cost. All elements that influence costs in the digital printing process both in sampling and production were identified and listed.

These elements form the basis of the cost model. When put together, each cost structure will yield a cost per square metre which can then be aggregated to produce a total cost per square metre. The total cost was calculated for both the sampling process and for the production process.

Once a model had been established for sampling and for production, the costs relevant to each were then directly compared. Furthermore, relevant data was entered to produce a cost model for production involving multiple shift work.

The cost structures, types and parameters pertaining to the digital printing process, both sampling and production were defined, determined and identified through a series of informal interviews with the managing director of the digital printing company and through observation of the digital printing process. All the elements of data concerning costs and variables were collected, separated out and categorised according to structures, types, parameters and function for the sampling process and for the production process. The data provided came from actual company records of the collaborating company. However in any cases where actual parameters or functions were not known, then searches were carried out to discover generic data and methods of calculating costs. The theoretical validity of such data, together with the categories identified, was then agreed with the collaborating company.

Ink consumption has been identified as a cost parameter and has been estimated independently by ink suppliers. Experiments were carried out in order to test the ink supplier's estimates and to therefore deduce a more accurate figure for ink consumption, thus enhancing the accuracy of the cost model.

Ink was printed onto a 200 cm^2 area of paper under the same conditions as production work. Different densities of inks were deposited onto the transfer paper. For example solid colours such as black and red, which deposited maximum saturation of ink, were printed, through to designs of mixed colours of varying saturations from heavy to light.

The paper was weighed before and after printing to establish the weight of ink being deposited. The rate of drying of ink was recorded over a 10 minute period, starting when the paper was removed from the machine after printing. This was done in order to determine whether the rate of drying was gradual or stepped.

Slow, gradual evaporation was found. This meant that the recorded weights gave reliable results because there was insignificant or no evaporation of fluid from the paper before it reached the scales.

The same approach as discussed above was used to determine the cost structures, types, parameters and functions of the transfer printing process.

A brief model of the transfer printing process was then created to determine the cost of transfer printing when used to process digitally printed paper. This cost was then used as a cost structure in the full cost model.

Using the agreed functions or agreed ways of calculating costs, the data collected concerning the cost types and parameters was then put into the relevant models (*i.e*. the sampling model and both production models of single and double shifts). The cost functions applied to the models then allowed the cost per metre square for each option to be determined.

RESULTS

The cost structures are the components of costs for the digital printing process. It has been established with the three companies that the cost structures are as follows:-

- Ink
- Machinery
- Labour
- Overheads
- Paper
- Transfer printing

The following tables list the established cost types, the cost parameters and the cost structures for the digital printing production and sampling processes: -

COST TYPES	UNIT OF MEASURE	COST FUNCTION
Ink	£	Mean ink price. I.e. Sum (ink prices/ number of inks)
Printer	£	Purchase price
Server	£	Purchase price
Software	£	Purchase price
Ink refill converter	£	Purchase price*number of inks
Machine Operators salary	£	Standard commercial rate
Transfer paper	£	Purchase price
Transfer printing	£	Cost derived from transfer printing model

COST PARAMETERS	UNIT OF MEASURE	COST FUNCTION
Inks	number	Fixed by machine specifications
Ink coverage	m^2/litre	Mean of experimental results
Machine Depreciation	£/month	Sum(printer,server,computer)+sum(ink refill converter costs)/depreciation period
Print Speed	£/m^2	Fixed by machine specifications * maximum fabric width
Machine Capacity	Hours	Hours per shift * number of working days per year
Machine Usage	%	Machine capacity per month * % down time
Machine Operators	number	Number of machines/number of operators
Work days	number	47 weeks*5 days
Overheads	£/machine	Total overheads apportioned between the CAD business and the printing business.

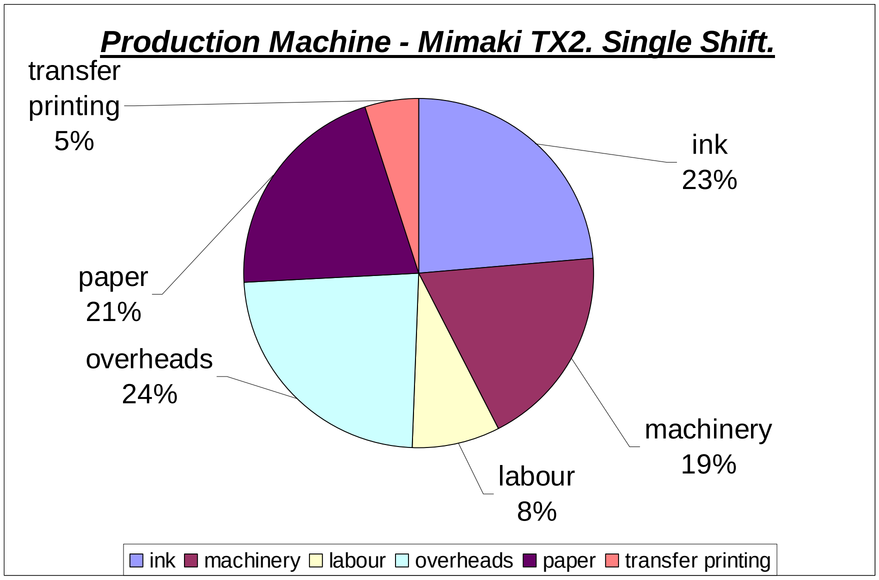
COST STRUCTURE	UNIT OF MEASURE	COST FUNCTION
Ink	£/ m^2	Mean ink price/ink coverage
Machinery	£/ m^2	Depreciation per month/m^2 produced per month
Labour	£/ m^2	Sum (machine operators per machine * by machine operator's monthly salary) / m^2 produced per month.
Overheads	£/ m^2	Machine hours per year /overhead rate
Paper	£/ m^2	Cost per linear metre * width of paper
Transfer Printing	£/ m^2	Cost derived from transfer printing model

Cost per square metre for each cost structure.
Using the cost functions above, each of the cost structures were calculated at a rate of £/m^2. The following table shows the cost per m^2 for each cost structure for sampling and production machines working single and double shifts.

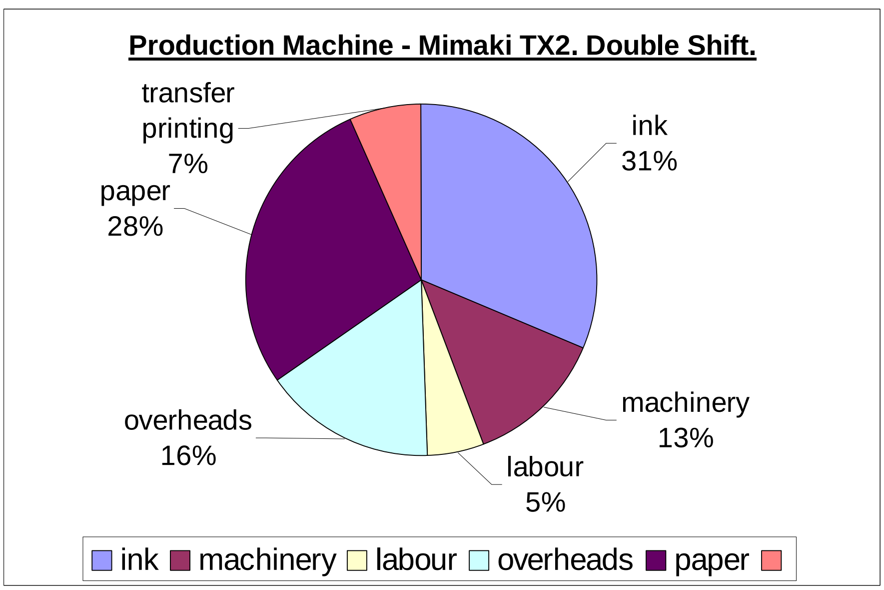
COST STRUCTURES	UNIT OF VALUE	VALUE OF COST STRUCTURE *SINGLE SHIFT.*	VALUE OF COST STRUCTURE *DOUBLE SHIFT.*	VALUE OF COST STRUCTURE *SAMPLING*
Ink	%	23	31	5
Machinery	%	19	13	17
Labour	%	8	5	10
Overheads	%	24	16	62
Paper	%	21	28	5
Transfer Printing	%	5	7	1
GRAND TOTAL	%	100	100	100

The above proportions are also represented in the following pie charts.

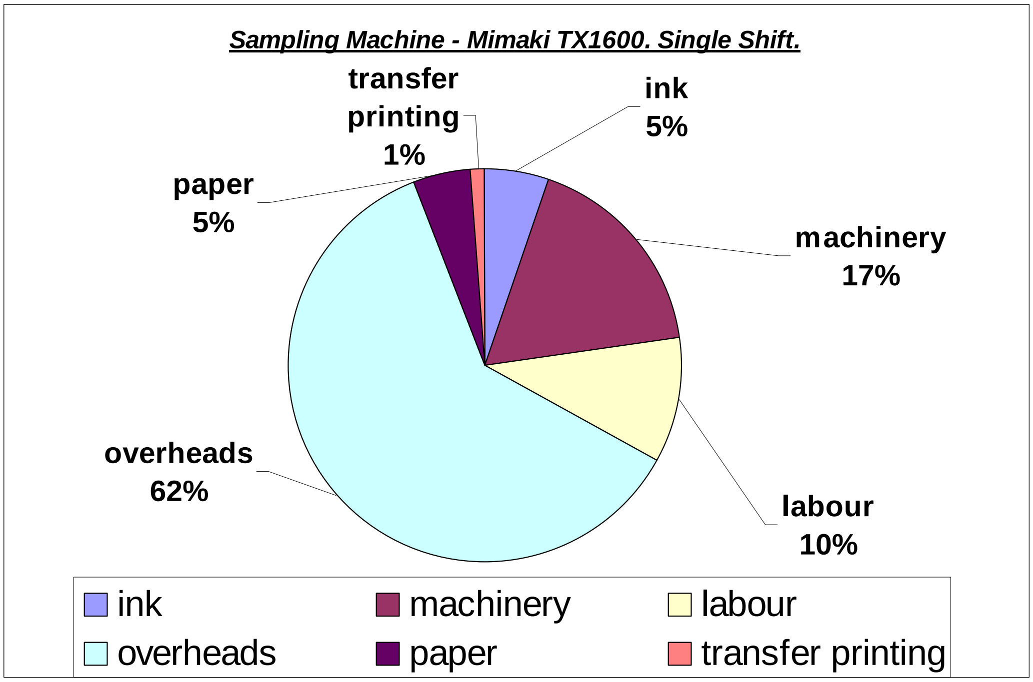
Value of cost structures. Production process: Single Shift.



Value of cost structures. Production process. Double Shift.



Value of cost structures. Sampling Process: Single Shift.



In order to assess the delivery of mass customisation for the interior textiles sector through digital printing, it is necessary to look at the commercial use of digital printing before the present project. That is for sampling and photoshoots.

By analysing the cost of digital printing as a sampling tool, the areas of cost which inhibit or enable digital printing as a production tool can be highlighted. For example, there is a significant increase in the cost of inks and paper per metre square when there is a move from sampling to production. Similarly, higher printing speeds reduce the cost per square metre. Inks, paper and machine speed are identified as the main inhibitors and enablers respectively in this analysis.

It should also be noted that, in the discussion of results, when making a comparison of sampling and production systems, the comparison used for production is based on the model for the single shift and not the double shift. This is because sampling uses only single shift working. The effects of shift work is discussed in the results but only in the context of the production system.

The significance of machine speed.

Machine speed is one of the decisive factors enabling the digital printing of textiles on a production scale.

The common point of comparison between commercial machines, advertised as being suitable for sampling, is the factor of printing speed. Machine speed is directly related to productivity. The number of metres that a digital printing machine can print per hour directly affects the output of printed fabric. The number of meters that can be produced per day, per week, per year is one of the determining factors in the cost price per metre. When the relationship between the machine cost, printing speed and output is presented in a cost model, a feasible cost price per meter can be determined which can then be directly compared to the cost model of a digital printing machine considered as a production machine.

It is necessary to understand that in digital printing, in its most basic form, the relationship between the machine speed and cost is one of the decisive factors enabling the digital printing of textiles on a production scale. Thus we can identify print speed as an enabler.

The costs of sampling
Machine speed appears to be a significant factor in the cost per m^2. The restricted volume that can be printed increases costs considerably, especially overhead costs. Our analysis shows that the speed of the sampling machine inhibits a cost-effective move from sampling to production and it suggests that faster machines are required for production.
The cost model for the sampling machine was created on the basis of the Mimaki TX 1600 machine, which has a print speed of 1.3 linear metres per hour and, consequently, it is commercially sold as a machine suitable for sampling.
When we look at the percentage portions of total cost per m^2 for each of the cost structures in the cost model for sampling, machinery costs, which are fixed costs, are higher than the other fixed costs such as ink, paper and transfer printing costs. This is due to the low maximum output of the machine in relation to capital costs.
The labour and overhead costs are variable costs that are specific to the particular business carrying out the digital printing of textiles. The overheads were worked out in relation to machine productivity and this revealed that the cost of overheads for sampling is high. Overheads have a significant effect on the final cost price per metre; although both fixed and variable costs would, in the majority of cases, remain very similar for any company using the same digital printing sampling machine.

It must not be overlooked however that there are also other variables, which become more critical and affect the cost effectiveness of the digital printing of textiles in the production process and these will also be discussed. However initially by analysing the sampling process we can see that the speed of the machine inhibits the cost-effective move from sampling to production.

It is thought then that the natural answer to enable the move from digital printing out from sampling to production would be to increase the speed of the machine and this has indeed happened, with each new machine on the market, appearing to have a faster printing speed than its predecessor. However, enhanced printing speeds will not solely facilitate the move from sampling to production as the intended evolution comes into play. The relationship between other variables and cost such as inks, paper, set up etc will be equally significant and critical and this will be illustrated in our discussions of the comparison between digital printing as a sampling tool and digital printing as a production tool.

By beginning with this brief analysis of the costs of digital printing as a sampling tool it has enabled us to follow the cost structures in the sampling cost model and progress from there to the production cost model. Thus, the analysis allows the viability of digital printing as a cost effective production tool to be explored.

Comparison of digital printing as a production tool versus sampling tool.

Inks. In sampling, the cost of ink is 5% of the total. Therefore, in sampling, management may not perceive the ink costs to be restrictive. However, in production the cost of ink is 23% and considerably more significant. The production route has nearly one quarter of the cost/m^2 coming from ink alone.

It seems that an obvious option in moving the digital printing of textiles from a sampling tool to a production tool would be to reduce the cost of the inks. This however would mean taking up pricing issues with ink suppliers in the hope of persuading them to reduce their manufacturing costs and their margins.

It is widely thought that, currently, within the industry, the ink suppliers are benefiting from a premium on the inks whilst at the same time trying to deny other ink supplier contenders by declaring warranties on machines invalid if inks other than those recommended are used.

Because the ink costs are significant within the production route, it is necessary that the ink cost per m/^{2} is known as accurately as possible and this was the reason for carrying out experiments to obtain more accurate ink consumption rates rather then using the manufacturers' estimates.

Actual ink consumption may be difficult to determine because the ink consumption depends on the print design. However when an average was taken from designs of differing dye saturation it was found that the consumption was very close to the estimates. Therefore it seems that the estimates of ink consumption provided by the ink suppliers appears to be quite realistic.

Ink and machine suppliers estimate that approximately 10g/m^2 of ink is consumed. Our results show that the mean ink consumption over a broad range of designs was 9.3g/m^2. However in both our examples and the estimates of suppliers, what is not allowed for in the cost model is the ink that is wasted in cleaning or unblocking the print heads. This could be included in the cost of maintenance, which is part of machine downtime.

Transfer paper. In sampling, the cost of the transfer paper is 5% of the total cost/m^2. Therefore, as with ink, in sampling the cost of paper may not appear too significant. For production however the cost of the transfer paper increases to 21%. This consequently becomes a significant cost in the final cost per square metre.

As the productivity of the machine increases, it generally lowers non-fixed costs such as overheads, etc., as printing more per hour amortises these costs. However as the paper is a static element its cost becomes significantly higher as the proportion of the non static costs reduce.

One solution to reduce the cost of the paper would be to use a less expensive transfer paper, which would mean using a thinner type of transfer paper. However, during the trials, it has been found that a thicker paper is needed to attain a quality print result. The purchasing price of paper equates to its thickness (*i.e.* the thicker the paper the more expensive it is).

As discussed previously with the inks, the costs of the paper are an issue that could be addressed by suppliers. Currently the cost of the paper is seen as an inhibitor in the production route for textile digital printing.

Cheaper paper across its range of qualities can have a significant effect on the final cost per metre in terms of reducing the final cost and therefore this could make transferred digital printing of textiles as a production tool more commercially viable and attractive.

If the paper costs are reduced then this can increase the commercial attractiveness of transferred digitally printed textiles.

Labour. In the sampling process the labour cost are 10% of the cost /m^2 and 8% of the cost per m/^{2} in the production model.
The digital printing process is not labour intensive; rather, it is machine intensive. Therefore the effect of the cost of labour does not show a significant difference when comparing the cost of sampling to the cost of production.
In production the labour costs are significantly lower than the ink and paper costs. Again this highlights the possible inhibitors in the production process, that being the ink and paper costs.

Overheads. The overheads in the model for the sampling machine are high, amounting to approximately 62%. One factor causing this may be the fact that the overhead costs can not be recovered due to the speed of the sampling machine. As the overheads are worked out as machine hour rate, (as digital printing is machine intensive rather than labour intensive) the print speed per hour will affect the cost of the machine hour rate. As the overheads have been apportioned between the total number of machines, it means that the sampling department, with its two machines, also has higher overheads than the production department from the outset and the costs of the overheads cannot be recovered due to the significantly slower speed of the sampling machine.
One way that Direct Textile Imaging reduces the sampling overheads is to charge a separate set up cost for each sampling job done.
The effects of such high overhead costs has, by comparison, made the ink and paper costs less significant, However it is due to the speed of the sampling machine that the overhead costs cannot be reduced and thus the ink and paper costs will always seem relatively insignificant in the sampling process.

In the production process a more realistic cost of overheads are seen. The overhead costs are 24% of the total costs. This again may be due to the fact that the speed of the machine and hence printing output is able to keep the costs of the overheads down to a lower level than sampling.
This then highlights the real costs of the inks and paper which are seen to be significant when digitally printing for production and thus again supports the fact that one of the enablers in the moving of digital printing from a sampling tool to a production tool is the machine speed.

Shift work. The effects of shift work are only considered for the production machine. As previously mentioned it would be unrealistic to consider the sampling machine in terms of a double shift as this would then create a production environment and the sampling machine is not economically viable as a production machine, as we have seen in the discussion of our results.

In a production environment, having the same machine run on a double shift will again reduce the overall cost per metre square
When our production model based on a single 8-hour shift was amended to a 16-hour shift the reduction in costs was approximately 26% on the total cost per m^2. It needs to be pointed out though that the machine operator has been costed in at the same rate for both day shift and night shift. In reality this may not be the case as night shift workers usually receive a premium on their daytime salary.

In the progression of digital printing, the nature of the digital printing process means that it is more machine intensive rather than labour intensive and with the creative use of available and relatively cheap technology the way forward may seem to be that the monitoring of the digital printing machine during the night could be done via web cam. However the question to ask in this case is “who will monitor the web cam?”
On the other hand though as digital printing machines develop it does not seem unreasonable to think that in the future the printing machine will be effective enough to work through the night without being monitored.
In the meantime, by re inputting the operators’ salary at 1.5 times the day shift rate, there is still a decrease in total cost of 22% which is still a significant decrease in the total cost per m^2.

If the production machine works a double shift the costs of ink paper and transfer printing costs will naturally increase because more product is being produced. The machine costs will decrease however because the machine will be utilised more. The increased utilisation will lead to an overall decrease in cost per m^2.

The issue of CAD work and the move to digital printing production.
The move to digital printing as a production tool is still in the very early stages, not only for Direct Textile Imaging but also within the evolution of digital printing production. Globally the majority of digital work carried out is still sampling work and this seems to have become relatively established.

As has been seen in the previous discussion of results, the cost per metre for sampling is significantly high with the cost of the overheads being the main factor. One way of recovering the overheads would be to charge an additional set up cost for the CAD work that is done on each specific sampling job and in fact this is the procedure for Direct Textile Imaging when carrying out sampling work.

Task 7: CUSTOMER WORKSHOP

Following on from the internal trial phase, a selected group of potential customers was invited to take part in a workshop which outlined the benefits and implications of mass customisation via digital printing. Potential customers were invited to assist in further trials to both increase pressure on the system capacity and expand the range of products.

A successful workshop was held in Rochdale Town Hall in which 55 people attended. This was targeted at people/companies who were either existing customers or potential customers. A representative of the Department of Trade and Industry was also present. There were five presentations within the workshop conducted by:

- David Tyler from the Manchester Metropolitan University
- Stephen Kay from Business Link North Manchester
- John Clegg from J Clegg & Bros. Limited
- Paul Noone from Direct Textile Imaging
- David Acton from Acton & Acton Limited

During the presentation, an extensive range of products was displayed and explained, illustrating a wide spectrum of textile digital printing products. A number of trial opportunities were established and supply contacts developed.

This wall hanging was unveiled at a meeting in Rochdale Town Hall in April 2003.

Task 8: REFINE PROCESSES

Customer trials were expected to reveal some further requirements not previously addressed by the 'internal trial' phase. The processes were refined in the light of these additional requirements.

Much interface activity has taken place during the trials with potential customers visiting/or called on by one or all three of our companies. A number of unexpected issues were identified - these issues would only ever shown up in 'hands on' activities and were unlikely to have been foreseen. These issues concerned colour management, saturation of colours, colour gamut issues, pixellation issues and the transfer process.

Task 9: REFINE COSTINGS AND SPECIFICATIONS

All lessons previously learned to date were factored in to an amended set of costings and specifications.

Trials have revealed that there are many facets involved in much of the development work that has made an exact costing specification potentially time-consuming. As a result, each company has a menu of costs, depending on their input. The specific amount is dependent on the particular product being produced. Using this menu approach, individual pricing/quotes are to be produced against every new job unless, of course, it is repeat business.

Task 10: NEW FABRICS

The fabrics used for the trial work to this point were all made from polyester fibre – although there were a variety of fabric constructions. This next phase of the project was to extend the product range in terms of both base fibre and fabric constructions available.

From a start up of a handful of polyester fabrics, the project partners now have a library of polyester cloths - woven, warp knit, weft knit, non-woven, and fleece microfibre in different weights and textures.

The collaborating companies have concluded that there is currently no commercial route for cotton or other natural fibres that can be developed for mass customisation products in interior textiles. It is, of course, technically possible to print other textile materials, but these are currently limited to photoshoot work and luxury niche markets.

This constraint is not a disadvantage in interior textiles: as polyester is widely used already and Trevira CS, the polyester fibre commonly used in the project, has the added benefit of being inherently flame retardant.

Task 11: ESTABLISH COSTING AND SPECIFICATIONS FOR NEW FABRICS

New fabrics will require new costing and specification data to be generated.

This task was dependent on Task 10. The cost model work can be developed to evaluate other routes are they become operational.

Task 12: WRITE FINAL REPORT

Manchester Metropolitan University was tasked with working closely with the SME partners to compile a detailed final report.

The report was prepared for the end of January 2004.

Task 13: DISSEMINATION

Dissemination activities were originally outlined in the full project proposal.

The project partners have achieved their proposed activities plus several additional events have been supported.

Innovation event - used as launch of the project	50 people
Rochdale Town Hall event for potential customers	55 people
CBE event on innovation	50 people
SDC conference	200 people
End-of-project event January 2004	40 people
Textile Institute Design Conference (April 1-2 2004)	[future event]

In addition, the report is being made available on the websites of the NW Advanced Apparel Systems Centre and the Industry Forum.

APPENDICES

APPENDIX 1:
ENVIRONMENTAL IMPACT OF DIGITAL PRINTING TECHNOLOGIES

Digital printing technologies are considerably cleaner than conventional ways of applying colour to textiles.

1. Digital printing machinery has no wasted ink/dye.

Conventional printing systems require colours to be mixed up and applied to the print roller/tray. Up to 50 metres of fabric/dye are used to ensure the dye goes on to the fabric correctly at the required speeds. After printing, surplus dyestuff is dumped. This has implications for effluent and cost. All this is avoided with digital systems.

2. The digital process has a higher fixation rate.

In conventional printing, the amount of dye placed on the substrate is not metred. It is extruded in sufficient quantities to do the job, allowing for some waste. Thus, if reactive dyes are used, a fixation rate of 65-70% would not be unusual. The 30% waste is because there are not enough sites on the substrate for the dyes to bind with. With digital technologies, the amount of dye put down is precisely controlled: and made just enough to do the job. The fixation rates are found to be higher, above 90%.

With disperse dyes, the situation is very similar. Transfer is efficient with the appropriate dwell time and transfer temperatures.

3. Conventional printing makes use of carriers that are later washed off.

Both reactive and disperse dyes have thickeners and carriers for the dye paste. After use, they are washed off as waste. These materials are not incorporated in the inks used for digital printing. With reactives, fabrics for digital printing require a “prepare for print” process, which puts a precisely monitored mix of materials on to the fabric to help achieve print integrity.

With other aspects of the processing (prepare for print and post-printing processes), there are no major differences to report between digital and conventional techniques.

The above comments are relevant to water-based inks. Digital technologies have also used solvent-based inks (but not on textiles). There are environmental issues with these inks. The cost of recovering the solvent requires machinery that is four times the cost of the printing equipment and also the operating costs are high. Solvent inks give no benefits to feed into the Kyoto Agreement or the Climate Change Levy.

The Swedish company Texdot AB is the first to receive the EU-Flower for its large format digital printer. This certificate is evidence that the production with the *GreenOne* is environmentally friendly according to the EU (REGULATION (EC)No 1980/2000 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL)

ECOLOGICAL PRINTED PRODUCT

· low air pollution

· energy efficient

· reduced toxicity

Licence registration number: SV/016/04

EUROPEAN UNION ECO-LABEL

From their web site at http://www.texdot.se

- **Ecologically superior production** (no solvent, no PVC > no hazardous waste)
- **No health danger for your operator** (not toxic fumes, print heads are cleaned with water)
- **Substantial savings in storage, transport, mounting, demounting and disposal** as the printing material is up to 5 times lighter than PVC
- **Lower site preparation and operating costs** as no climate control is necessary and print heads have extremely long life expectancy (no consumables!)
- **Marketable advantages to your clients:** positive image effects by using green prints, lower disposal/storage costs, easier handling.

Appendix 5: A VISION OF THE FUTURE

Digital printing technologies have experienced rapid change during the past decade, and since 1990, commentators have been anticipating that the sector will "take off". Nevertheless, it has taken three years for this prediction to sound convincing. The ITMA 2003 exhibition in Birmingham, UK, was a significant milestone for digital printing, with 27 companies offering textile digital printing equipment. Many of the machines shown were said to print at over 50 m^2 per hour, and the Reggiani printer (regarded as the "star" of ITMA 2003) was said to print at 150m^2/hour (The production rates for all machines is dependent on the resolution selected by the operator).

Applications for digital technologies may be analysed in three categories:

1. Sampling and photoshoots. This is the traditional application area and this may be expected to continue with modest growth.
2. Bulk production for batches less than 1000 metres. This is the vision of many, and interest is at what point digital technologies can "compete" successfully with screen printing.
3. Mass-customisation. The creation of new niche markets for small-medium batches of printed textiles for specific customers. This is the application area for this project.

At a post ITMA event organised by the Manchester and Cheshire Section of the Textile Institute (11th December 2003), the subject of digital textiles was discussed at some length. Major contributions to this discussion came from Derek McKelvey of M&S. Derek spoke of digitally printed garments in their Spring 2004 Autograph collection. M&S have worked with fabric suppliers Kaldor Fabrics, garment suppliers Velmore, and Stork Digital Printing. Samples were printed in Holland by Stork and 1000 metres of fabric were printed in Taiwan. Make-up is in Morocco. The garment is a two-tier silk chiffon and silk crepe de chine dress.

Derek McKelvey spoke about the average print run in Europe being about 800 metres (larger in Asia). The vision is for digital printing to gain market share at the expense of screen printing for lengths up to 1000 metres. "Think of the implications for printers if garment makers decide to buy a digital printer and attach it to a laser cutting table". Printing could then be located close to garment manufacture and linked to the marker plan to save up to 20% of dye. After printing, the fabric could be cut single ply using a computerized system and then made-up. The comment was made: "next year some digital printers will be available that will be faster than conventional printing". Also, the "main obstacle to wider take-up of digital printing is high dyestuff cost".

This vision of the future relates to (2) above. Digital printing machines could either be "super machines" with high productivity, or simpler workhorses that can be used in parallel or independently. The Bangkok unit mentioned above has 25 Stork Sapphire machines run much like a traditional weaving department.

Whilst (2) is of interest for the development of digital printing as a technology, there is not necessarily a positive message here for UK manufacturers. Whilst retailers perceive an advantage in sourcing offshore, they are likely to do the same with digital applications. The UK interest is likely to be in niche markets, where the design potential of digital can be fully exploited. This is category (3) above.

APPENDIX 6: GLOSSARY

<table>
<tr><td>CIE</td><td>The international organisation concerned with light, vision and colour. The acronym is from the French: Commission Internationale de l'Eclairage (International Commission on Illumination)</td></tr>
<tr><td>CIELab</td><td>The CIELab object is primarily a storage contaimer for colorimeter data in the CIE Lab colour space. The L*-axis represents lightness and extends from 0 (black) to 100 (white). The other two coordinates a* and b* represent redness-greeness and yellowness-blueness respectively. Samples for which a* = b* = 0 are achromatic and thus the L*-axis represents the achromatic scale of greys from black to white. The following diagram depicts the basic colorimetric structure of the a*b* values:

Yellow
(+b)
|
|
|
|
|
|
|
Green (-a) ------------+------------ (+a) Red
|
|
|
|
|
|
|
(-b)
Blue</td></tr>
<tr><td>CMYK</td><td>A colour mode made up of cyan (C), magenta (M), yellow (Y), and black (K). CMYK printing produces true blacks and a wide tonal range. In the CMYK colour mode, colour values are expressed as percentages; therefore, a value of 100 for an ink means that the ink is applied at full saturation.</td></tr>
<tr><td>Cockling</td><td>Surface distortion in paper (or fabric) caused by localised stresses in the material. Paper cockling is often linked to uneven shrinkage or unstable humidity levels. The cellulose fibres swell due to the absorption of moisture, resulting in an uneven, wavy surface that persists after drying.</td></tr>
<tr><td>Colour</td><td>A quality of an object you can see, depending on the light reflected from it.</td></tr>
<tr><td>Colour Difference</td><td>The magnitude of the difference between two object colours under specific conditions.
$\mathbf{\Delta E = \Delta L + \Delta a + \Delta b}$</td></tr>
<tr><td>Colour Separation</td><td>In commercial printing, the process of splitting colours in a composite image to produce a number of separate greyscale images, one for each primary colour in the original image. In the case of a CMYK image, four separations (one for cyan, magenta, yellow, and black) must be made.</td></tr>
<tr><td>Colour Space</td><td>A geometric space, usually of three dimensions, in which colours are arranged systemically.</td></tr>
<tr><td>Gamut</td><td>The range of colours that can be reproduced or perceived by any device. For example, a monitor displays a different colour gamut than a printer, making it necessary to manage colours from original images to final output.</td></tr>
<tr><td>Hue</td><td>The attribute of colour by means of which a colour is perceived to be red, yellow, blue etc. Pure white, black, and greys possess no hue.</td></tr>
<tr><td>Light fastness</td><td>The ability of a material to withstand colour change on exposure to light.</td></tr>
<tr><td>Luminance</td><td>The luminous intensity (expressed in cd/m^2) of any surface in a given direction per unit of projected area of the surface as viewed from that direction.</td></tr>
<tr><td>Nanometer (nm)</td><td>Unit to describe wavelength, where 1nm = 1/1000000mn.</td></tr>
</table>

Pantone Colours.	An international reference system for the specification of colour, offered by Pantone, Inc.
Pixellation	A type of image distortion in which individual pixels are discernible to the naked eye, or groups of pixels display as blocks of colours. Pixellation is caused by incorrect resolution, by incorrect image dimensions, or it can be created intentionally for a special effect.
RGB Colour	A colour mode in which the three colours of light (red, green, and blue) are combined in varying intensities to produce all other colours. A value between 0 and 255 is assigned to each channel of red, green and blue. Monitors, scanners, and the human eye use RGB to produce or detect colour.
Saturation	The strength or amount of the hue – how much the full hue is desaturated with white.
Scanfile	A computer file for an image that contains all the raw data about that image in pixel format.
Spectrophotometer	Photometric device for the measurement of spectral transmittance, spectral reflectance, or relative spectral emittance
Sublimation	A form of transfer printing employing dyes that sublime readily and have substantively for the substrate to which they are applied.
Opaque	Transmitting no optical radiation, you can not see through the material.
Wavelength	An electromagnetic wave, the distance in the direction of propagation between nearest points at which the electric vector has the same phase.