SEVENTH FRAMEWORK PROGRAMME
NMP-2007-3.1-2
New added-value user-centred products and product services

SERVice Oriented Intelligent Value Adding nEtwork for Clothing-SMEs embarking in Mass-Customisation

D6.2a Automatic Knitting Sites pilot

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Document description	Demonstrator report and SME business proposal for Customised Knitwear as a result of the Automatic Knitting sites pilot, that was conducted in the framework of Task 6.2.

Executive Summary

This report describes the outcomes of research and development work done by IFTH (France) and Nottingham Trent University (UK) to develop and evaluate the procedures for a business model to produce commercially customised fully-fashioned knitwear. It builds on the initial work done by Unicatum, RWTH and Hohenstein Institute (Germany). The purpose was to demonstrate the commercial potential for on-demand, localised manufacturing of up-market fashion products using new technology.

The target market was upper-middle market knitwear for ladies, typical products being a jumper, cardigan or dress. As with the rest of the SERVIVE project, customisation has been assumed to be linked to style advice. Thus part of the overall product and consumer experience is the initial process of co-design. This is partly illustrated in the video of the demonstration [see http://www.youtube.com/watch?v=WIodKyciJAM]. However as this could vary according to each retailer (e.g. web-based or personal style advisor, product category, etc.), this aspect is better covered in other SERVIVE project deliverables.

The key technology assumed in the micro-factory is one or more whole-garment 3D knitting machines. It is recognised that this can be an option with circular knitting (e.g. Santoni), but in this instance the focus is on the multiple flat-bed technology such as is available from Stoll and Shima Seiki. This equipment, plus the necessary finishing machinery, was available at IFTH's Troyes facility. The demonstration used the style advice and product specification expertise at NTU in conjunction with IFTH production expertise to test the concepts. Several different types of garment were successfully made for real people with great variations of style, colour, size, and trim detail.

The results indicate that it is practical to produce customised luxury knitwear from start to finish in less than 2 days, with an indicative price band of €300-€500. Though it is possible to do this with one whole-garment machine, for efficient staffing and machine utilisation an SME micro-factory with a minimum of 2 machines is recommended. This would facilitate an annual throughput capacity of 2,000+ garments. An investment of around €0.5 million could generate an annual turnover of a similar amount, and a satisfactory profit.

Table of Contents

List of Figures

List of Tables

1. Introduction

The Knitwear Demonstrator sub-project is part of Work Package 6 (WP6), and is intended to show practical results of the research and development involved in the SERVIVE project.

The original work in this area was done by the SME partner Unicatum, but as they were unable to complete the task, IFTH and NTU were asked to fill the gap. The Troyes facility of IFTH is based in the traditional knitwear area of France, and has a wide range of machinery and manufacturing skills, including both Stoll and Shima Seiki 3D whole garment knitting equipment. NTU has a world-wide reputation for its fashion knitwear courses, and substantial design expertise.

The revised Demonstrator plan was somewhat limited by the need to compress all the work into the last 6 months of the SERVIVE project. Nevertheless the task was to show how a range of product types (based on a dress and jumper) could be customised to the unique requirements of examples of the target consumer group. This target customer would be female, and probably somewhat older and better-off than the average High Street shopper.

Initial work involved developing some design ideas, thinking about yarn types, and exploring the capabilities of the whole-garment knitting machines available. The normal process of development with cheap yarn such as acrylic was rejected as being inappropriate for the target market. A high-quality merino wool yarn type was chosen. The options of 3D knitting of style features such as pockets was explored, and compared with separate manufacture of such items on more traditional fully-fashioned knitting machines for later attachment. Programming requirements of various fabric features and constructions were developed. Discussions between designers and technicians took place via tele-conferences and visits, to develop a good understanding of options that could be offered in the customisation process.

This enabled the Demonstrator Workshop to be planned with confidence.

2. System model

The context for the investigation into the viability of customised knitwear is as described in the SERVIVE project proposal, and the subsequent refinement of the target products and consumer sector. The aim is to satisfy the demand from those who can afford to spend a bit more than the average for something made just for them. In this case the product sector is knitted outerwear that market research has indicated should be classic but fashionable, a so-called 'investment piece' that could be worn for many years.

In diagrammatic terms, the system process flow is as follows:

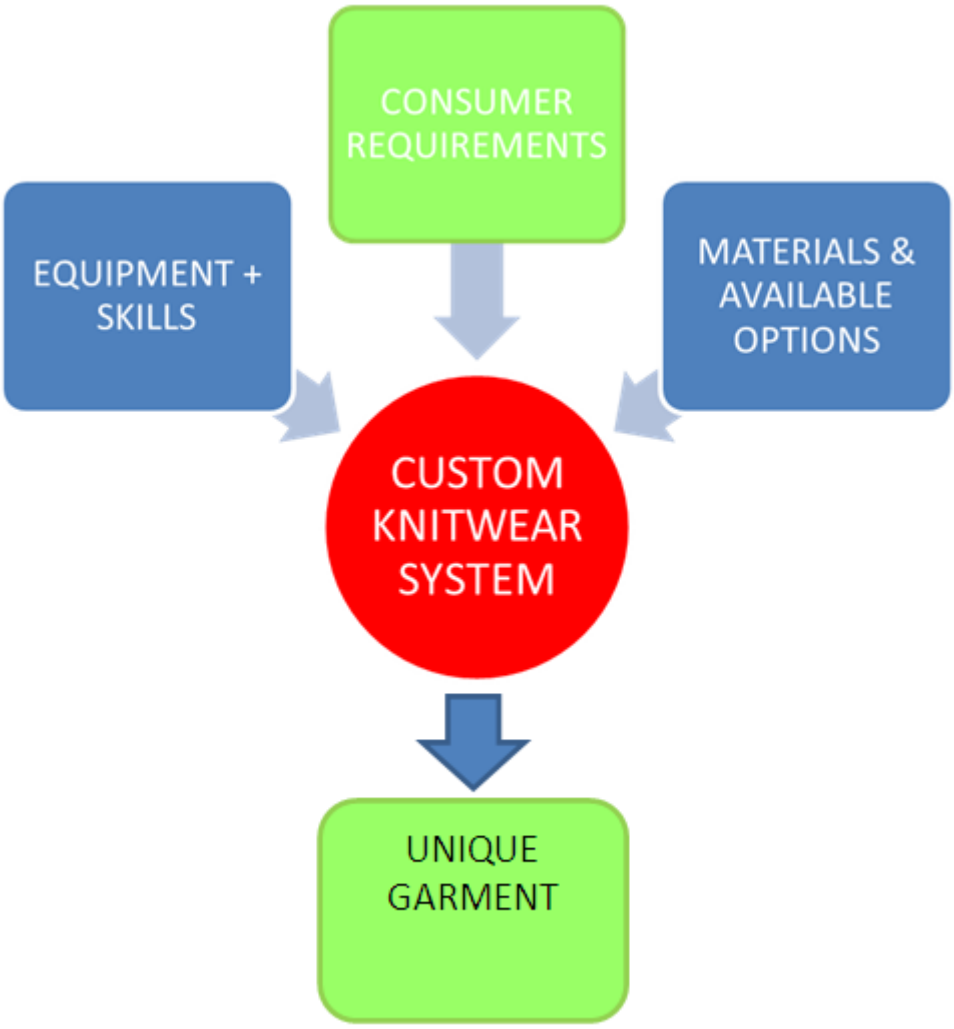

Figure 1: System Process flows

Consumer requirements will be influenced by style advice as well as size, shape, colouring and fashion attitude. System constraints will exist through both yarn and trim materials availability, and knitting machinery capabilities.

The purpose of this project is to demonstrate the practicalities and possibilities through exploring real examples, testing limits, and developing a model of a small or medium-sized (SME) business that could exploit such a system.

3. Customisation process flow

This customised knitwear process can be further broken down into the following stages:

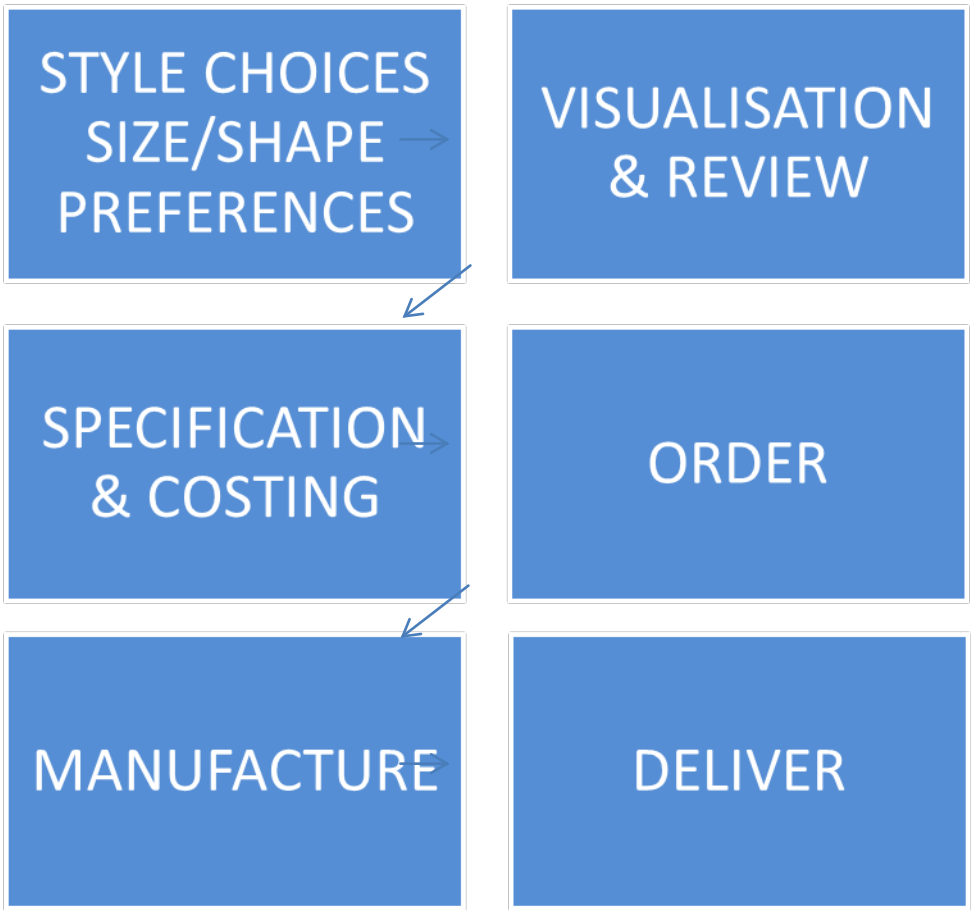

Figure 2: Customised knitwear process

Aspects such as a full 3D computer-aided visualisation of a person's style choices mapped on to their own avatar are outside of the scope of this part of the project. Nevertheless it is envisaged that this will be a valuable part of the ultimate ordering process.

This is because research has shown that the two greatest concerns of consumers buying customised product are

i) financial (cash committed before final product can be seen); and
ii) product suitability ('will I look good; what will friends & family think')

Thus it seems highly desirable that a customer has the confidence of a good image of the ultimate product. For further information on this 'virtual try-on' aspect, it is recommended to refer to the work of other SERVIVE project partners such as MiraLab, Digital Humans, and CustoMax.

Physical examples of similar styles, materials and colours can also help customers make choices in this respect. Yarn and trimmings samples or fabric swatches can be a great help, even if all details are not exactly identical to the final requirements.

For size and fit, a try-on garment of a similar size to that required would be the norm in a traditional retail environment, until a repeat customer has developed confidence in the fitting process. It may be that in due course this could be automated from 3D body scan data, though for this knitwear work a few basic measurements are enough given the flexibility of knitted fabric.

For this report and demonstrator sub-project, the process starts with design choices that lead to the product specification. Visualisation and review were by the more traditional means described above. Style advice was provided by fashion knitwear experts from NTU. This role in a traditional retail environment would be played by an experienced shop assistant, perhaps with contributions from the customers trusted friends.

In this case there was no 'customer order'. In a commercial environment, it would be expected that the order would have the following components:

- final product specification
- costing
- predicted image / virtual garment
- contract (including payment details, deposit, etc.)
- delivery arrangements (perhaps progress monitoring as well).

4. Design and specification

The scenario assumes that brand / retailer / micro-factory can offer a limited number of 'base' styles, but with many options of a variety of variables. Even if they were as few as 10 options of each of 6 variables, there would be a million possible combinations. It is highly likely that any one combination would therefore be unique.

Note that the core product offering is inevitably limited by the gauge and hence capability of the knitting machine. A fine-knit 28-gauge fabric cannot be made on a machine with too few needles per inch. The IFTH machines could produce the equivalent of around 10-12 gauge, so the base designs were targeted more towards this area. In this case, the three base styles of jumper, cardigan and dress were effectively reduced to two by using similar machine programming for the dress and the jumper, and differentiating primarily by length of the garment knitted.

Figure 3: Cardigan sketch

Figure 4: Dress/ jumper sketch

Each of these base styles is almost infinitely variable because of the flexibility of possible knitted structures and cabling effects in the fabric itself. For the demonstration, just a few patterning options were programmed, with limited positioning options (such as top of sleeves, centre front or back). This is in addition to the cuff and hem options.

Style features and variants in these cases included items such as pockets, sleeve length, collar type, belt (knitted separately), trim and colour combinations.

Yarn type, quality and colour can all be varied. For this demonstration, the preferred yarn for the machinery gauge available was 2/28s. Colours were selected from the Autumn/Winter 2011/12 range, and restricted to 8 options in line with the perceived 'classic – fashion – investment piece' target market requirements. Yarn quality was merino, with an even more expensive option of cashmere/silk/merino blend.

Sizing in both length and girth could be +/- a stitch [in this case – 10 or 12 gauge equivalent – this means approximately +/- 2 mm]. Given the elasticity inherent in knitwear, it might be assumed that fitting options are totally flexible. However with certain fabric patterns this may not be the case. It may be a design feature that a whole number of pattern repeats is needed to look 'right'. This can impose restrictions or require adjustments elsewhere, such as in the length of the hem or cuffs, or the amount of plain fabric around any pattern.

For garments such as the cardigan, trimming and finishing options include buttons & button-holes. These are done afterwards, but again can allow multiple choices. Note that commercially it would also be necessary to sew in labels. Fibre content and care instructions plus perhaps even a personalised brand label could be expected, though obviously these were outside the scope of the demonstration work.

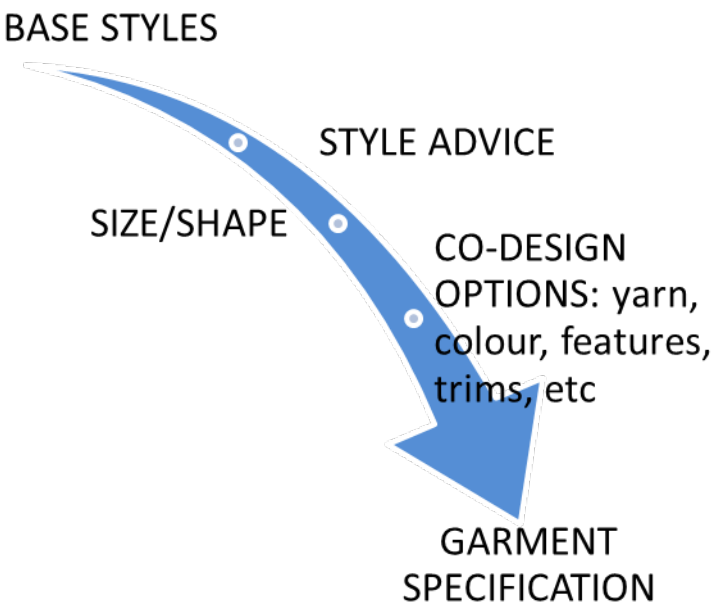

Figure 5: From base styles to garment specification

This process results in an outline specification for the garment. At this stage there could be a provisional bill of materials and list of operations for its manufacture. However, unless the garment is simple and relatively standard, it will be necessary to adjust the program for the electronic whole-garment knitting machine.

The features offered as part of the co-design process would need to have been tested beforehand with respect to the knitting programming. Invalid programs can cause machine damage, while untested programs can give undesirable outcomes such as incorrect sizing.

5. Pre-production

The traditional processes of mass-production generally involve multiple trial-and-error prototyping to develop a reliable program for the knitting machine. In this case, the aim is to produce the correct garment first time. If a mistake is made or a prototype required, this would double the cost of the garment. Thus it is essential that at each stage of the process, there is an appropriate quality control procedure to ensure that ultimate production of the garment is error-free.

There are 4 key stages before knitting can start, namely programming, materials procurement, cone preparation, and knitting machine set-up.

5.1. Programming

This is the key stage where the garment design is translated into instructions for the electronically controlled knitting machine. Both Sheima and Stoll have their own proprietary computer design systems that provide the machine control information. This includes presser foot control and transfers between needle beds that enables 3D shaping to be done. The machines involved in the demonstration each had twin needle beds each with 700-800 needles per bed, plus up to 16 yarn feeds. To govern the action of every needle and yarn feeder for every stitch is clearly complex, given that there are typically several hundred thousand stitches per garment.

The programming task requires an understanding of the knitting technical processes, and training in the specific machine package. It is thus a highly skilled job.

Normally each design feature would be attempted and prototyped. This is done before any final production is attempted. In this case a certain limited number of parameters and options had been tested. This was then fed back into the co-design process as a more restricted set of options. This constraint applies to items such as the design and position of fabric structure effects, collar types, and even the sizing of the garment.

The prototyping of new design options can take many hours, plus the use of the knitting machine in testing. For a customised design using pre-tested parts of a program this process of producing a control disk for the machine is much quicker. It could still nevertheless take up to an hour of the technician’s time.

5.2. Materials procurement

The garment specification, along with the program, defines the yarn requirements for knitting. This is not just the total amount of yarn of each colour but also the number of cones of each. This is defined by the number of independent yarn feeds the design requires. Different fabric patterning, garment features, and colour combinations can all have an impact on the number of cones required. With customised garments it is very likely that this will change from one garment to the next.

Yarn quantity is normally expressed in grams or kilos, as it is sold by weight. Yarn is used by length, and there is always a standard yarn count quoted (weight per unit length). Note that this is an area

of quality control closely linked to cost control. Yarn weight can be affected by atmospheric conditions, the addition of lubricant to aid the knitting process, as well as variations in the spinning process.

5.3. Cone preparation

A full cone of yarn might typically weigh 1 kg. A whole garment might weigh only 0.5 kg, while the design could require 12 feeder cones as was often the case for the demonstration garments. It therefore is sometimes sensible to re-wind yarn on to a smaller package rather than break in to a full cone every time, and risk additional degradation and waste that can occur with opened packages.

A yarn re-winding machine is not absolutely essential, but it is a relatively quick and simple operation that makes sense in this context.

Figure 6: Yarn cones

Figure 7: yarn re-winding

5.4. Machine set-up

For both Stoll and Shima machines, the set-up required to change from one style to another is similar. The cones of yarn need to be loaded and threaded through the needles, and the control program has to be installed. In mass production it would be normal practice to load full cones, replace occasionally as necessary, and continue to knit repeat garments with the same program all shift long. There would thus be no set-up time from one garment to the next.

For customised garments, as with this demonstration, almost everything needs to be changed after each item is knitted. This process can take 10-15 minutes.

It is likely that the draw-thread yarn that is necessary at the start and end of the knitting process can remain the same. Otherwise it can be assumed that all the main cones have to be swapped out. It is believed that Shima have an optional device that can automatically re-thread the new yarn into the needle bed, but this was not the case here.

Re-programming the knitting machine is relatively straight forward in terms of transferring the program; this is by floppy disk, and the machine's workstation.

Figure 8: Re-programming the knitting machine with floppy disk

Figure 9: Using the workstation to re-program the knitting machine

6. Knitting

The Stoll and Shima machines are similar but different. Each requires a skilled mechanic who has had the appropriate training to operate, as was seen in the pre-production procedures. In this case it was fortunate that IFTH had two operatives with the necessary skills, each with his own specialist preference for one machine or the other.

Once the machine is set up, with the correct yarns threaded to each of the 720 needles and the design program loaded, the machine can run automatically. Occasional checking is normally done in case a problem occurs (e.g. yarn breakage), but normally no further intervention is required.

An adult-sized whole garment might take 50-60 minutes to knit. Larger and more complex styles could take over an hour; simple garments might be completed in less than 40 minutes.

Figure 10: Automatic knitting machine garment production

Note that for some garment styles, there may be components that are best knitted separately on a conventional machine. In this demonstration for example, this was the case with pockets, belt and button stand options for the cardigan. These are attached as part of the finishing and second make-up processes.

7. Finishing

Once the knitting process has finished, there are several stages that the garment needs to go through before it is in a finished state for the customer. These ensure that yarn ends are trimmed, any knitted components added, fabric is conditioned and cleaned (for example removing any yarn lubricants necessary for the knitting process), adding trims such as buttons, labels and any embroidery features.

7.1. Off-machine trim

The 'top and tail' rows of knitting needed to start and finish the garment need to be removed, along with residual connecting threads from the 3D knitting process.

This might take the knitter 2-3 minutes following the unloading of the garment from the knitting machine.

Figure 11 Off-machine trim

7.2. Steam

In order to relax and even out any knitting tensions in the fabric, it is standard practice to flatten and correctly shape the garment on a steam table. Steam is gently blown through the garment as it is positioned correctly and flattened into shape. The vacuum mode of the table allows removal of excess vapour afterwards.

This process requires both the steam table equipment, and takes a few minutes.

Figure 12: Steam

7.3. Second make-up

Most garment styles will require additional assembly processes, such as the attachment of trims. One of the demonstration styles, the cardigan, had options for pockets and a belt as well. In this case the items were knitted separately, but then needed to be attached by means of either a linking machine or an over-locker.

Any commercial system would need to ensure correct coordination of sub-assemblies, and the costing of the skilled time required for such tasks.

7.4. Wash

In order to remove any lubricants from the knitting yarn, it is normally necessary to wash the garment. This is done in a typical household washing machine, with the appropriate washing powder or detergent for the fibre type, and at the recommended temperature.

Figure 13: Wash

With the quality wool-rich yarns used in the demonstration, the stage which took the longest was the garment drying. Generally the garments were dried flat, overnight.

7.5. Trim and finish

All garments will need some additional machining to finish them. Obvious examples would be labels, buttons and buttonholes, hanger and belt loops, perhaps even customising embroidery such as initials, though none was needed for this demonstration.

Buttons and button-holes were added in the general sewing machinery section. This is also the stage at which garment labels would be attached (washing /care instructions, composition, brand).

Figure 14: Trim and finish

Clearly these would all need the appropriate sewing machinery and a multi-skilled operator to do the job. A time allowance of 10 minutes should cover this.

These are examples of the garments produced for the demonstration:

Figure 15: Examples of the garments produced for the demonstration

8. Pack and despatch

Part of the customer experience is the receiving what might be thought of as a present to themselves. Therefore it would be worth paying attention to the packaging and presentation of the final garment. A good example to follow is that of Matteo Dosso. They use tastefully designed boxes, compliments slip, and wrapping paper to enhance the delight of receiving something special.

It is assumed that quality control procedures have been effective enough to ensure all is as it should be. Nevertheless some system should be in place for the possibility of complaints or returns.

More likely, there would be advantage in adding items to help a satisfied customer spread the word to friends for future orders.

9. Business model

The business model outlines nine essential and inter-related elements in the process of designing, making and selling mass customisation. All of these must be balanced and aligned to achieve success within a given market (figure 16).

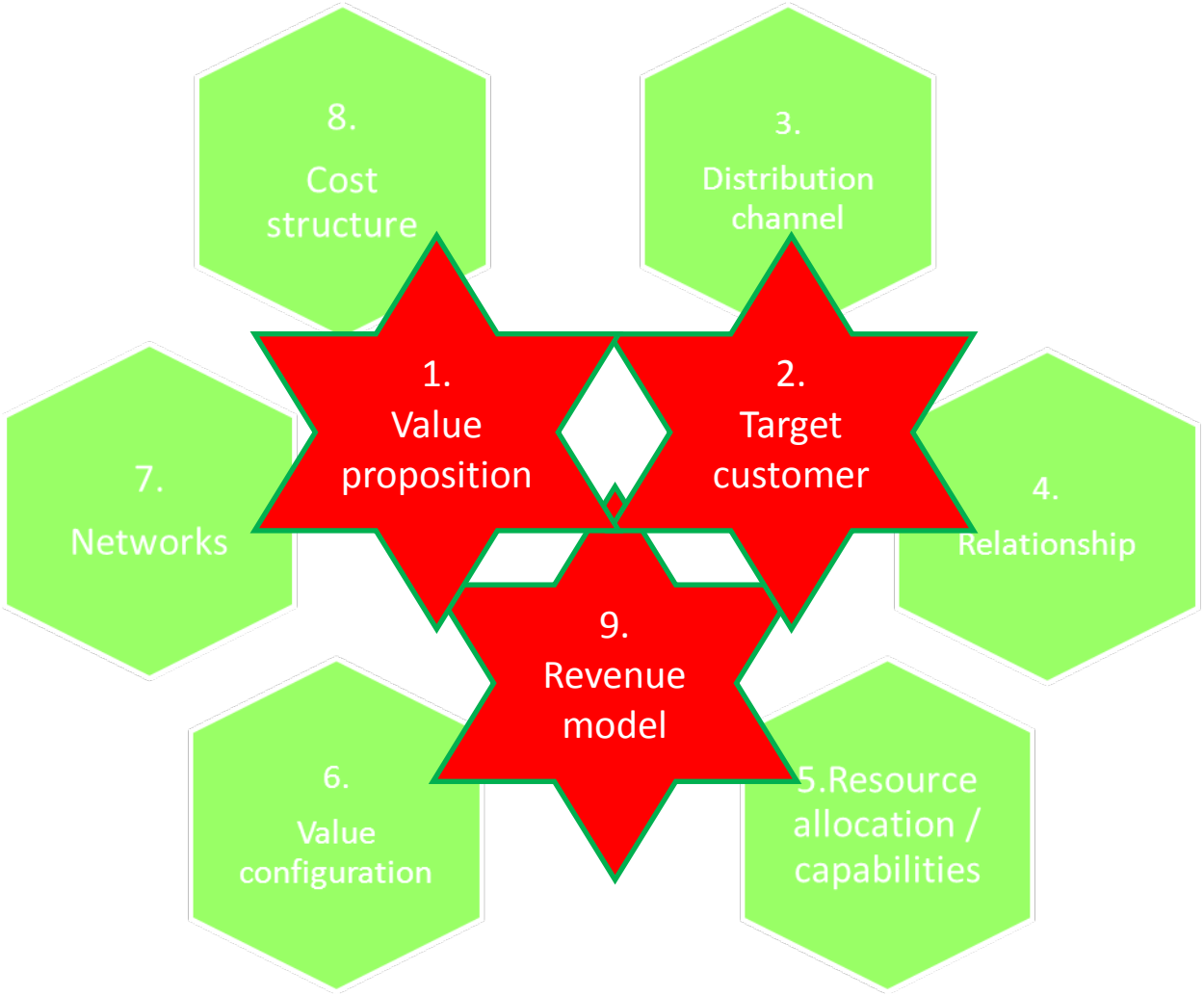

Figure 16: Nine Business Model Building Blocks[1]

9.1. Value proposition

We can summarise the overall value proposition for knitwear mass customisation as:

> ***giving each individual customer the choice of knitted product which exactly satisfies their needs and wants, within a reasonable period of time, and at affordable cost.***

This is a balancing act, requiring compromise between the level of customisation technically possible and desirable, and the trade-off concerns of cost and speed. Providing the level of customisation that meets customer needs involves also managing the process to ensure that costs and timescale meet expectations.

[1] Adapted from Osterwalder et al 2005

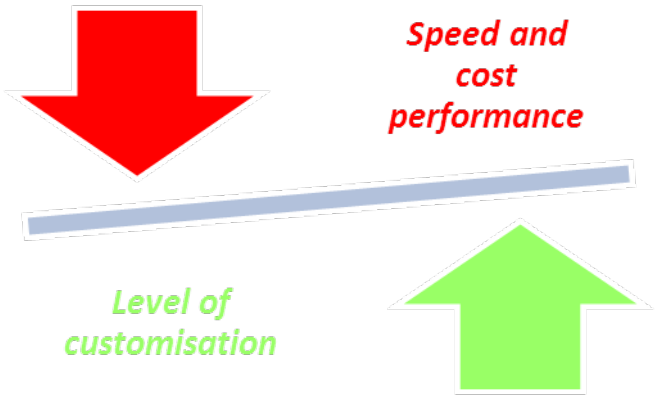

Figure 17: The mass customisation trade-off

The 'appropriate' level of customisation is determined by the customers' needs and a sound understanding of what genuinely does 'add-value' for the customer. A look at the knitwear catalogue (autumn/winter 2011) of a major UK department store gives an insight into what customers potentially do value for off the peg knitwear!

However, evidence suggests that providing customers with too many customisation options can make their decision making process confusing, leading to delay and even the possibility that they will not purchase. The differing extent to which knitwear can be customised is illustrated in figure 18 below and explained in the accompanying table.

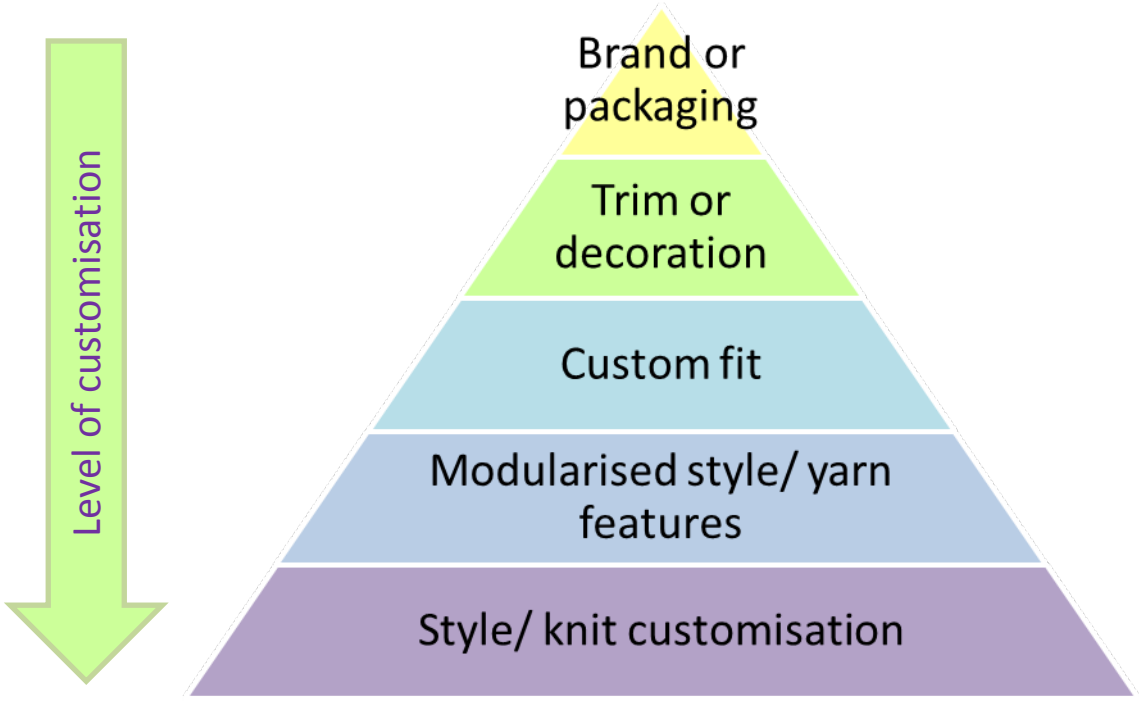

Figure 18: How much customisation?

Degree of customisation	Type of customisation	Example
1	Pack, brand or packaging	Combinations of items packed together (eg hat and scarf) or brand label applied
2	Trim or decoration	Name or logo embroidered onto sweater
3	Custom fit	Made to measure adaptation of a base style - including non-standard size pattern adaptation
4	Modularised style/ yarn features	Select pre-defined collar, pocket options for a base style or choose yarn from stock or preselected options
5	Style/ knit customisation	Customer co-design of base style or knit detail

Table 1: Degree of customisation

9.2. A Blueprint for mass customised knitwear.

The following blueprint provides a step by step checklist of things to consider when planning a mass customisation system for knitwear. The steps are broken down into the nine elements of the business model and provide a range of options for each step based on the level of customisation.

The most effective system should be broadly aligned to the customer needs and value proposition, but this will vary for specific elements. Moving towards the left hand column of the matrix will potentially reduce costs and speed up response time. Moving to the right hand column provides more freedom to explore the increasing range of technical and design capabilities that the latest technology allows.

Elements of the business model beyond the product configurations must be considered. Key to ensuring customer satisfaction is in building confidence in the product which is unseen at the point of order, and enabling the customer to make an informed decision about which style/fit options to choose to maximise their enjoyment of the product. These aspects are considered in terms of relationship building, customer interface and style advice, and core capabilities.

The business model matrix has been applied to the knitwear demonstrator process and the working model is shown in Annex I.

9.3. The Blueprint explained

The matrix (opposite) summarises options for the first 7 elements of the business model.

1. Value proposition

What is being offered to the customer? Mass customisation can range from customising the final presentation of the knitwear to enabling the customer to influence the design stage. True co-design could entail bespoke programming and post-design testing which adds cost and time to the process. A number of options to limit the co-design process can be considered:

1.1. Labelling and brand, confined to finishing and packing (p15-16)
1.2. Trim and final stage customisation, confined to second make-up and finishing (p16)
1.3. Size and fit customisation (p7)
1.4. Colour and yarn customisation (see demonstrator guide p8-9)
1.5. Surface texture/ pattern customisation

2. Target customer

Understanding the customer, what motivates their desire for mass customised knitwear and predicting their buying behaviour is essential to knowing how to target the other elements of the business model. Assuming a female market a number of customer profiles can be targeted, with differing buying behaviours and needs:

2.1. Personal goals and aspirations from all purchases
2.2. Identified need/ trigger for wanting customisation

3. Distribution Channel

According to the target customer, appropriate options for getting the knitwear to the market need to be planned and negotiated. This also impacts upon

3.1. Targeted complementary promotional events

4. Relationship

Building an on-going relationship with customers is essential to the mass customisation process, as part of the standardisation opportunity relates to repeat business allowing modifications to be repeated and future needs anticipated. At core, the loyalty ladder prioritises regular and repeat customers, aiming to convert these to advocates by…:

4.1. Maintaining customer contact and communications
4.2. Providing style advice, information and guidance
4.3. Dealing with returns/ problems
4.4. Responding to Post-purchase feedback

The Blueprint

	Mass				**Customised**
1 MC type	Custom pack/ label	Trim/ decoration	Adapt fit	Adapt style	Co-design
1.1 Pack /label	Size/wash label only	Customised retail label	Customised brand label	Customiser's own label	Customer own label
1.2 Trim	Switch button/ stitch colour	Add motif/ logo	Add custom finish	Add custom trim	Change band/edge
1.3 Fit	Alternative size/ length options	Choose modular sleeve welt length (S/R/L)	Adapt sleeve/ welt length Add/ remove rows	Choose modular garment length/ breadth	Custom size/fit
1.4 Style	Choose colour from list	Choose yarn from stock	Choose modular collar/ pocket/ belt	Choose modular sleeve, hem, neckline	Custom re-style
1.5 Co-design	Style/ pattern/ texture predefined	Choose all over texture/ knit from catalogue	Choose stripe/ intarsia colour; use predefined swatches	Change panel size of pattern/knit	Custom knit design
2 Client	Buying for close friend / relative	Home/ office worker	Managerial/ professional	Affluent business / professional	Aspirational young professional/ Wealthy 'other'
2.1 Why buy knit	Feel good factor/ gift	Stand out from the crowd	Solve fit problems	Individualistic/ exclusive	Statement piece
2.2 Why MC knit	Regular gift purchase	Every day with a twist	Satisfies need	Satisfies wants	Aspirational
3 Retail outlet	Supermarket/ mall shop-in-shop/online	Chain store added service/ online	Department store/boutique/online	Specialist boutique/ online	Fashion café/ boutique
3.1 PR	Mall demonstration	Press coverage/ introductory discounts	Special event/ B2C exhibitions	Charity event/ Product placement	Celebrity fashion show/ endorsement
4 Relat-ionship	Prospect	Customer	Client	Client/ advocate	Advocate
4.1 Tools	Loyalty card	Repeat purchase offers	Maintain fit records	CRM / events	CRM/ invitations
4.2 Style Advice	Newsletter	Modular fit advice	Online Fit advice/ styling	Community of interest	Catwalk fashion news
4.3 Return policy	Discount & return to sale stock	Discount & return to sale stock	Accept return only if fit is not as agreed	Accept return only if style not as agreed	No return
4.4 Post purchase	Feedback survey	Feedback survey	Online review	Follow-up phone-call	Seasonal party/ fashion show

Blueprint continued……..

	Mass				Customised
5 Core resources	Flexible finish/pack department	Flexible finishing department	Pre-designed and tested fit options	Pre-designed and tested styles	Flexible design /programming
5.1 interface	Online order platform from options	Online order from options	Online order with personal advice/ or demonstrator	Online order with personal advice/ or demonstrator	Personal advice backed by online system
5.2 Brand identity	No brand/ retail brand extension	Retail brand extension/ 'shop-in-shop' brand	Fashion brand extension/ customiser own brand	Fashion brand extension/ customiser own brand	Designer brand extension/ or under license to customiser
6 how is value added?	Base model + Finishing	Base model + modular accessories	Base product + fit adjustments	Base product + modular style changes	Base design stage only
6.1 Base product	Limited number tried & tested products. Limited size/ length options	Small seasonal range of tried & tested base products. Pre-set size/lengths	Small seasonal range of tried & tested base products.	Small seasonal range of tried and tested base products	Designs change regularly – new styles require testing
6.2 Modules	Finishing options only – limited choice of buttons, stitch, labels…	Added trims / embellishment – limit choice of button, collar, belt, motif….	Pre-determined adjustment points – bust, shoulder, hip, sleeve, length	Inter-changeable style details – sleeve, pocket, welt, knit pattern	Co-design of integral details within machine gauge limit(s).
6.3 Materials / supply	Predefined colour/ pattern options. Choice of trims from stock	Choice of yarn & colour; knit & texture defined by machine gauge. Choose from stock	Choice of yarn & colour; knit & texture defined by machine gauge. Choose from stock	Choice of yarn & colour; knit & texture defined by machine gauge. Choose from stock	Choice of yarn & colour; knit & texture defined by machine gauge. Choose from supplier catalogue
6.4 Demand manage-ment	Dynamic pricing/ batch auction/ incentive prices	Dynamic pricing/ incentive prices	Targeted marketing	Targeted marketing; customised pricing	Targeted marketing; customised pricing
7 Partners	Supply and retail partners	Supply and retail partners	Vertical manufacture/ distribution	Vertical manufacture/ distribution	Vertical manufacture/ distribution
7.1 Supply manage-ment	Pre-ordered yarn from roll-over supplier selection	Pre-ordered yarn from seasonal supplier collection	Pre-ordered small batch yarn inventory – replenished on demand	Pre-ordered small batch yarn inventory – replenished on demand	Yarn available to order; Open source design
7.2 Retail partners	Supply to retail outlet	Supply to retail chain	Shop-in-shop	Own outlet/ shop-in-shop	Own outlet

Table 2: The Blueprint explained

5. Core capabilities

What resources are needed at each stage of the implementation plan? This includes aspects of flexibility in manufacture (page 10) as well as:

5.1. The customer interface – technology platform to a skilled personal stylist
5.2. Branding – ranging from none, through existing brand to specialist 'customiser' brand. The value of branding can be seen at

6. Value configuration

How is value to be added? The overall mass customisation strategy has at its heart a 'base' product or design, which is developed to differing degrees according to the level of customisation that will be added. Added customisation involves a number of process stages including:

6.1. Key to the base product is the integrated 'testing' which underpins product confidence and quality (see p6 and 8). This effectively limits the number of base options available.
6.2. Modules – interchangeable modifications that can be applied to the base model according to predefined and tested specifications (page 7)
6.3. Materials – Yarn, trims and added style details need to be within the machine gauge limitations and also agreed delivery/ inventory policy (page 9).
6.4. Demand management stimulates customers to order, encompassing pricing and communications to appeal to different customer groups. Differential demand management helps to maintain a regular order schedule by attracting customers when capacity is available.

7. Partner network

The mass-customiser is essentially at the heart of a network of suppliers and distribution, all of which enable successful fulfilment of customer added-value.

7.1. Relationship with suppliers is integral to ensuring that yarn/ trims are available, the level of choice is appropriate, in-stock inventory provides the necessary buffer, but is otherwise at a minimum and replenishment is accommodated (page 8).
7.2. Relationships with retailers ensure that the mass-customisation platform is visible and accessible to the widest audience of targeted customers, and that revenue generation supports the MC concept.

8. Cost structure and revenue model

Cost structure and Revenue model are discussed in section 10 below, where the Business plan is analysed.

10. Business Plan

It is assumed that there is potential demand for customised knitwear along the lines of this demonstration. Clearly there are many possible variations of the market sector. One suggestion was for example for golfwear, this being a market segment where more affluent consumers might be willing to pay a bit extra for exactly the right garment for them. Some knitwear brands already do offer a level of customisation, from designer brands to knit for functional purposes and workwear.

The business plan is generic in that reasonable assumptions are made of costs & time involved. Some specifics are quoted, but it should be viewed as an outline business proposal that could easily be adapted to any more specific case, consistent with the business model above.

10.1. Product cost

As with any product, cost can be broken down into materials, labour and overheads. With one-off customised manufacture, in can be expected that these items will be not quite as efficiently used compared to a mass-production line.

Thus wastage of the main material (yarn) might be around 10% rather than 2%. A knitting mechanic may be expected to operate half the machines he would look after in a traditional factory – perhaps less if there is major programming work needed for each item. This would also be reflected in the intensity that the capital employed could be used. The investment in production facilities, particularly knitting machines costing over €100,000 each, would be spread over fewer saleable items, so increasing overheads.

These factors have been allowed for in the following calculations.

a) Materials: yarn

- approx 0.5 kg per item + 20% waste
- merino cost ~€30 per kg [2]
- 0.5 x 120% x €30 = €18

Materials: other

Other materials costs will be small compared to the knitting yarn. Some items such as buttons and thread will be style-dependent; others such as labels and packaging are variable. An allowance of €5 can be assumed.

This would give a total material cost for the examples illustrated above in section 6 of around €23. It should be noted that this is a little more than for a mass-produced item. However, mass-produced, ready-to-wear clothes have other areas of systemic waste. There is rarely a 100% sell-through rate, and there is 'shrinkage' in the logistics and retail distribution system. Thus overall there is likely to be little difference in the total supply chain material cost compared to a one-off customised product.

[2] Note that the cheapest acrylic yarns might be only €5 per kg, but this would not be appropriate for the target market. It is more likely that cashmere and silk blends costing over €100 per kg would be an option. This could push the main material component to over €60 per garment

b) Labour

Any work involved in the co-design stage can be regarded as part of the product ordering or contract development process, and is outside of the scope of this demonstration. It may be part of a retailer's traditional shop activity, or could be web-based and thus involving just the customer's time.

These costing calculations are based on the activities that can be directly associated with the micro-factory scenario.

Process	QC	Time		
		Labour	Machine	Elapsed
Factory order (clerical)	check specification	20 mins	0	1 hr
CAD Program modifications	use prototypes	10-20 mins	20 (CAD)	1 hr
Yarn issue	inspect	5-10 mins	0	
Knit m/c set-up	as program	10 mins	10	
Knit	visual	5	50	1 hr
Trim	visual	5	0	
Make-up options[3]		?	?	
Steam	measure	10	0	0.2
Wash	ref. yarn type	5	0	2 hrs
Dry	"	5	0	12 hrs
2nd make-up	sample machinist	10-20	0	1 hr
Pack & despatch	check order	10-20	0	1 hr
			TOTAL	**19.2 hrs**

Table 3: Costing calculations

Some labour can be seen as administrative / clerical, some for an expert knitting technician, some for a skilled sample sewing machinist, some semi-skilled factory assistant grade. The most expensive key skills are those of the knitting technician. This person who is needed for both the CAD programming and for operating the knitting machine will have had appropriate training with focus on one system supplier (in this case either Stoll or Shima).

It is possible to supervise several knitting machines concurrently. This is normal in mass-production factories. In this case, it may take a total of around 30 minutes of the technician's time plus an hour of machine time per garment. Thus one person could manage 2 knitting machines (plus CAD work station). A reasonable maximum output at 75% loading would therefore be 2 x 6 = 12 garments per 8 hour shift. Around half the time would be program preparation on the CAD work station; the rest would be machine set-up, occasional checking, unloading and trim/inspection for knitting quality.

[3] possible option items such as pockets, belt, button stole, collar etc. might be knitted separately and then attached by linking or over-locking. Note that these sorts of items can be knitted on standard fully-fashioned machines, without using capacity of the specialised 3D equipment – see 7.3 second make-up.

The rate of pay would vary according to local conditions, but if it is assumed that in Europe an skilled hourly rate of €30 would include normal on-costs, a direct labour garment cost would be

8/12 hrs per gmt x €30 = €20 per garment

The other direct labour would consist of service functions such as materials stores (receipt, issues and returns), washing & drying, 2nd make-up sewing, packing and despatch. This would total perhaps an hour per garment, though could be expected to average a lower semi-skilled rate of perhaps €20 per hour. If the total labour in these areas is 45 mins, then this cost is

3/4 hrs per gmt x €20 = €15

The total of 20 + 15 = €35 assumes optimum loading, and a standard costing model.

It is probably more realistic to assume average throughput is less than this, but the skilled work force would still need to be paid. It would be prudent to assume order levels will fluctuate. Quiet times should be devoted to further product development to extend the range of options that could be cost-effectively introduced to future customers and demand management (See 9.3) used to even out demand.

c) Overheads

The overheads will consist of the administrative staff, and particularly the factory and equipment costs. The following estimates are based on what might be a plausible scenario for a micro factory. Note that it could be possible to operate with just one 3D knitting machine. However, this has its risks. It is assumed that as knitting technical expertise is a key requirement, it is sensible to employ a minimum of two people in this area. Some cover would be possible for holidays and other absences, as well as increasing capacity.

As each could look after 2 machines, then 4 whole garment knitting machines could be run concurrently. Alternately, 2 machines and 1 CAD work-station could be run on 2 shifts to improve capital utilisation, though obviously shift work in a small company has other complications. It is recommended that the machines be of different gauges to extend the possible product range.

Assuming 2 machines, each over €100,000, plus assorted finishing and ancillary equipment and CAD work station, the total investment in premises, systems and machinery could be assumed to be approximately €400,000 to start with. With depreciation of 10% and perhaps €20,000 allowed for servicing and parts,

Depreciation	= €40,000
Maintenance	= €20,000
Total	= €60,000 p.a.

Office staff and general services and expenses might be €100,000 p.a. so that total overheads could be €160,000 p.a.

For this to be spread over the number of garments sold on the year, it is necessary to estimate a realistic sales /production total. In order to generate this, it is assumed that the micro-factory unit

might operate on 1.5 shifts [e.g. 7am – 3pm + 11am – 7pm with a 4 hour overlap]. This would give 24 hours whole-garment machine time per day as the capacity constraint. As before, with 75% maximum utilisation, this gives a maximum of 18 garments per day.

Thus the weekly total capacity would be 90 garments; or for a full year of 46 weeks = 90 x 46 = 4,140 p.a.

It is possible with a full 2 shift system, or with overtime, this figure could be exceeded. However, it is more likely that the average sales for such a non-mass production business would be much less. Assuming 2,000 garment per year [i.e. around 50% capacity loading], the factory overhead per garment would be €80 [160,000 ÷ 2,000].

Garment costing summary

Materials	=	€23
Labour	=	€35
Overheads	=	€80
Total	=	€138

Thus the 'factory gate' cost for the micro-factory SME with the assumptions and approximations above would be €138.

Given typical retail mark-ups and gross profit margins, such garments might be expected to retail at price points of several times as much. For example, at €400 the gross margin would be around 65%; at €500 the gross margin would be 72%. These prices are in line with branded off the peg knitwear available, for example at Selfridges on Oxford Street.

Clearly costs are very volume-dependent given the high investment needed in the various items of modern equipment. However, a business plan that envisages growth beyond the cautious 50% capacity envisaged here, based on only 2 main machines and 1.5 shifts, could show excellent long-term profitability.

This would need to be planned in relation to a consumer-facing or retailer revenue model.

10.2. Revenue Model

The revenue model covers the mechanism used to generate income, maintain customer loyalty and ensure sustainable running of the operation.

To some extent this will be contingent on the method of distribution, but assuming that for mid-to-high levels of customisation this is likely to be through a retailer-owned shop in shop, boutique or online format, some generalisations can be made. Key points include:

- Customer pre-order contact
- Customer order point
- Processing payment
- Customer second contact point – delivery
- Customer closing contact point – return or feedback
- Maintaining customer contact

These 6 key stages can be explained as follows.

1. Customer pre-order contact is essential to provide style advice, information and manage expectations – for example how much customisation or co-design is available? At this stage basic information about delivery, ordering and refund policy should be transparent (though not fore-fronted). Customer testimonials and reviews are increasingly incorporated into on-line platforms to help build customer confidence at this stage. Visual appeal is important, and a virtual demonstrator (see for example MiraLab/Digital Humans and CustoMax project deliverables) would help significantly to enable customers make a wise decision.

2. Customer order point – this needs to be easy to use, and to provide the customer with a clear and concise statement of EXACTLY what has been ordered – including specification of all customisation options selected. Again a visual representation would be helpful. Previous research has shown that this stage is crucial in building customer confidence in proceeding with a customised product order. If modular or customised costing is used this should also be transparent and clearly stated.

   At this point the refund or return policy must be clearly stated, and customers asked to POSITIVELY ACCEPT the stated terms and conditions.

3. Processing payment may take place in two stages. If a deposit is taken, the balance to be paid should be clearly stated and details of how/ when payment is expected. If the deposit is non-returnable this should be stated in the terms and conditions (above) and re-iterated at the point of payment.

   The final payment should be taken before or on delivery of the goods, and the returns policy restated.

4. Customer second contact – delivery of the goods or collection in store. Quality assurance should provide the mass-customiser with confidence that the goods are as stated, and the customers' expectations will have been managed. This should lead to a positive customer experience, the aim being to delight the customer: exceed expectations rather than just

meet expectations if possible. Quality of service, personalised packaging and offer of add-on purchases can all enhance the experience. However, there will always be exceptions:

5. Customer returns or complaints should be handled sensitively but firmly, and the above policies should avoid circumstances where customers have genuine grounds to be dissatisfied. However, in the event that the customer is disappointed with the style, fit, quality or look of the items, the non-refundable deposit MUST be retained. If the customer has genuine reason to feel that the goods are not as described or ordered then good customer service – and in some cases – legislation, should dictate that an unquestioned refund is given. The potential wastage cost of returned items must be included in the business plan, as customised product cannot be "returned to stock" like ready-to-wear items.

6. Customer loyalty can be fostered in a number of ways. Generally financial incentives can help to generate loyalty; while listening, making customers feel involved and valued, can help to sustain loyalty.
    a. Financial incentives might include money-off next sale, 'introduce a friend' incentives, multiple purchase discounts, or a loyalty points membership scheme with stated associated benefits.
    b. Creating a community of interest can help ensure customers stay loyal. Proactively gaining feedback, publishing customer reviews, photographs, stories of what customers did in their new customised knitwear, could all help. But negative feedback must be acted upon. This may also require public relations policing of web sites such as Facebook and Twitter.
    c. Other mechanisms include regular style news, invitations and related product offers. A customer relationship management system (CRM) might also be employed to suggest using left over yarn and down time to make add-on accessories or to revamp previously supplied garments.

11. Conclusion

The practicalities of manufacturing customised fully-fashioned knitwear have been demonstrated. The relationship of 3D whole-garment machines to the rest of the production process, pre- and post-knitting, has been shown in the context of a range of cardigans, jumpers and dresses.

Figure 19: Range of garments produced by the Automatic Knitting site pilot

Product details were co-designed with several typical consumers, covering variations of size, shape, colouring, and fashion attitude. Style details have been shown to be flexible, but with certain constraints governed by

- machinery type (gauge and capability)
- yarn and other materials availability
- pre-tested knitting programs
- ancillary equipment and skills

The revenue model will clearly need to be modified for the exact detail of the business configuration. This could be multiple retail outlets sharing the resource of a single micro-factory (or multiple micro-factories), pure web-based e-tailing, or even the SME micro-factory dealing directly with the public.

As far as the overall concept is concerned, a business and technical model has been successfully developed that could deliver customised knitwear to the target market at an affordable price.

Annex I: Mass Customisation Blueprint in action: The Knitwear Demonstrator

	Mass				**Customised**
1 MC type	Custom pack/ label	Trim/ decoration	Adapt fit	Adapt style	Co-design
1.1 Pack /label	Size/wash label only	Customised retail label	Customised brand label	Customiser's own label	Customer own label
1.2 Trim	Switch button/ stitch colour	Add motif/ logo	Add custom finish	Add custom trim	Change band/edge
1.3 Fit	Alternative size/ length options	Choose modular sleeve welt length (S/R/L)	Adapt sleeve/ welt length Add/ remove rows	Choose modular garment length/ breadth	Custom size/fit
1.4 Style	Choose colour from list	Choose yarn from stock	Choose modular collar/ pocket/ belt	Choose modular sleeve, hem, neckline	Custom re-style
1.5 Co-design	Style/ pattern/ texture predefined	Choose all over texture/ knit from catalogue	Choose stripe/ intarsia colour from predefined swatches	Change panel size of pattern/knit	Custom knit design
2 Client	Buying for close friend / relative	Home/ office worker	Managerial/ professional	Affluent business / professional	Aspirational young professional/ Wealthy 'other'
2.1 Why buy knit	Feel good factor/ gift	Stand out from the crowd	Solve fit problems	Individualistic/ exclusive	Statement piece
2.2 Why MC knit	Regular gift purchase	Everyday with a twist	Satisfies need	Satisfies wants	Aspirational
3 Retail outlet	Supermarket/ mall shop-in-shop/online	Chain store added service/ online	Department store/boutique/online	Specialist boutique/ online	Fashion café/ boutique
3.1 PR	Mall demonstration	Press coverage/ introductory discounts	Special event/ B2C exhibitions	Charity event/ Product placement	Celebrity fashion show/ endorsement
4 Relationship	Prospect	Customer	Client	Client/ advocate	Advocate
4.1 Tools	Loyalty card	Repeat purchase offers	Maintain fit records	CRM / events	CRM/ invitations
4.2 Style Advice	Newsletter	Modular fit advice	Online Fit advice/ styling	Community of interest	Catwalk fashion news
4.3 Return policy	Discount & return to sale stock	Discount & return to sale stock	Accept return only if fit is not as agreed	Accept return only if style not as agreed	No return
4.4 Post purchase	Feedback survey	Feedback survey	Online review	Follow-up phone-call	Seasonal party/ fashion show

Denotes the level of customisation selected for/ appropriate to the demonstrator unit.

Blueprint continued ……

	Mass				**Customised**
5 Core resources	Flexible finish/pack department	Flexible finishing department	Pre-designed and tested fit options	Pre-designed and tested styles	Flexible design /programming
5.1 interface	Online order platform from options	Online order from options	Online order with personal advice/ or demonstrator	Online order with personal advice/ or demonstrator	Personal advice backed by online system
5.2 Brand identity	No brand/ retail brand extension	Retail brand extension/ 'shop-in-shop' brand	Fashion brand extension/ customiser own brand	Fashion brand extension/ customiser own brand	Designer brand extension/ or under license to customiser
6 how is value added?	Base model + Finishing	Base model + modular accessories	Base product + fit adjustments	Base product + modular style changes	Base design stage only
6.1 Base product	Limited number tried & tested products. Limited size/ length options	Small seasonal range of tried & tested base products. Pre-set size/lengths	Small seasonal range of tried & tested base products.	Small seasonal range of tried and tested base products	Designs change regularly – new styles require testing
6.2 Modules	Finishing options only – limited choice of buttons, stitch, labels…	Added trims / embellishment – limit choice of button, collar, belt, motif….	Pre-determined adjustment points – bust, shoulder, hip, sleeve, length	Inter-changeable style details – sleeve, pocket, welt, knit pattern	Co-design of integral details within machine gauge limit(s).
6.3 Materials / supply	Predefined colour/ pattern options. Choice of trims from stock	Choice of yarn & colour; knit & texture defined by machine gauge. Choose from stock	Choice of yarn & colour; knit & texture defined by machine gauge. Choose from stock	Choice of yarn & colour; knit & texture defined by machine gauge. Choose from stock	Choice of yarn & colour; knit & texture defined by machine gauge. Choose from supplier catalogue
6.4 Demand manage-ment	Dynamic pricing/ batch auction/ incentive prices	Dynamic pricing/ incentive prices	Targeted marketing; modular pricing	Targeted marketing; customised pricing	Targeted marketing; customised pricing
7 Partners	Supply and retail partners	Supply and retail partners	Vertical manufacture/ distribution	Vertical manufacture/ distribution	Vertical manufacture/ distribution
7.1 Supply manage-ment	Pre-ordered yarn from roll-over supplier selection	Pre-ordered yarn from seasonal supplier collection	Pre-ordered small batch yarn inventory – replenished on demand	Pre-ordered small batch yarn inventory – replenished on demand	Yarn available to order; Open source design
7.2 Retail partners	Supply to retail outlet	Supply to retail chain	Shop-in-shop	Own outlet/ shop-in-shop	Own outlet

Denotes the level of customisation selected for/ appropriate to the demonstrator unit.

Note the demonstrator accommodates a high level of customisation, reflecting technical capability and anticipated customer expectations.