Mass customised fashion

Development and testing of a responsive supply chain for mass customised fashion garments

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This thesis is for Doctor of Philosophy in Textile Management
Mass customised fashion
- Development and testing of a responsive supply chain for mass customised fashion garments

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Acknowledgement

I started my academic career at the School of Engineering at the University of Borås in 2001. After my master degree in logistics 2006 I started my doctoral studies at the Swedish School of Textiles, still at the University of Borås. It has been five very fun years were I have got the chance to travel all over the world, meet interesting people and learn interesting things. During these five years a number of people have influenced me and my research and you deserve a Big thank you! So thank you:

- my family and friends for being supportive during the research process. Even though you may not have understood what I have been up to, you have provided me the confidence and the security I needed to undertake the task of writing a dissertation.
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Sincerely yours

[Signature]
Abstract

The background to this thesis is the dynamics and institutions of the fashion world. They have developed out of reasons of convenience and on the whole they work, but there are possibilities of improvement. Time from style and colour-direction to market is up to 18 months, from design to market 12 months and from forecast to market six months. With such long lead-times, there will be a few inherited problems such as matching supply and demand and offering sizes to people with non-standard body shapes. Some of the problems are related to mass and volumes, it is simply not possible to produce garments that fit everybody’s needs and to keep them in stock. The result of the long lead-times and need for mass and volume is low forecast performance, a forecast error of ±40% six months prior to the season is not unusual, which in turn leads to a sell-through percentage of about 60 percent.

To address some of the problems of the fashion world a research initiative called Knit on Demand has been developed. It is a research project at the Swedish School of Textiles, in collaboration with the knitwear manufacturer Ivanhoe AB and the fashion retailer SOMconcept AB. The purpose of the project was to “...develop and test a new production and logistic solution for agility in customer relations.” To fulfill the purpose of the project, a supply chain for customised knitwear was set up and then tested. Customers customised and bought their garments at SOMconcept in Stockholm; the order was then transferred to Ivanhoe who produced the garment and then delivered it to the customer within a couple of weeks. The supply chain has been analysed on supply chain performance, customer behaviour, design and technology. In addition to the Knit on Demand supply chain, SOMconcept’s other products have been analysed and a simulation of Shima Seikis Ordermade system has been performed.

The methods in the thesis are mostly qualitative with elements of quantitatively. An action research methodology was applied to develop the project and then a number of case studies and simulations.

The results show that most of the customers that are purchasing mass customised garments are niche customers that would have problems finding garments that fit them in the conventional fashion outlet. Important to the customers are service in the store and the experience of customising their garments. Since a mass customisation concept works on niche markets it would benefit from the Long Tail economy that gives better access to niche customers.
Appended papers

This thesis is based on the work contained in the following seven papers, which are appended in full and referred to in the text by the Roman numerals I, II, III, IV, V, VI and VII:

**Paper I**

**Paper II**

**Paper III**

**Paper IV**

**Paper V**
Larsson, J. (2011) Customer perspective on mass customised knitwear, *accepted for publication and resubmitted* to Journal of Fashion Practice

**Paper VI**

**Paper VII**
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1 Introduction

This chapter introduces the reader to the fashion business in general and to why the thesis is written by presenting the background to the related problems in the fashion industry. It aims to narrow the scope of the fashion business in general down to the Knit on Demand project, which is the focus of the thesis but also to the additional research cases. State of the art examples of similar projects are also presented in order to familiarise the reader with the researched area.

1.1 Background

The background to the research presented in this dissertation is the fashion market, its institutes and the dynamic between its different actors. The fashion market has developed to its present form, much due to reasons of convenience and institutes such as the fabric fair Premieré Vision, the fashion fair Bread and Butter and trend watcher bureaus such as London based Worth Global Style Network (WGSN) and Paris based Promostyl, which are important actors of the fashion world. These dynamics might seem strange on the outside, for example, the need for constant change, here addressed by Oscar Wilde in *Woman's World* November 1887:

*And, after all, what is a fashion? From the artistic point of view, it is usually a form of ugliness so intolerable that we have to alter it every six months.*

Since there is a need for constant change, the fashion industry has to address it. It is convenient for the industry if trends do not change too much every season and if overall trends are somewhat in the same direction. Because if every actor on the market would decide the next trend by himself, it would all become very complex to handle. The most convenient way to manage trends is a forum that decides what will be trendy the following seasons. It also makes it easier for marketing experts to prepare customers for needing the season’s must-haves. Figure 1.1 illustrates a general model of the fashion industry. The model consists of the following two flows: 1) the left flow is the fashion companies; and 2) the right flow is the marketeers. It is based on the work by Davis-Burns and Bryant (2005), Hedén and Mc Andrew (2005), Jackson (2007) and Webb (2007).
Figure 1.1 General model of fashion supply business.

Eighteen months ahead of a season a fashion forecasting service provides colour and style direction to fashion companies and to fabric and raw material suppliers. The trend institutes style and colour directions, which are illustrated in Figure 1.2 (style) and Figure 1.3 (colour).

Figure 1.2 Style direction A/W 12/13 men’s casual wear (Coleman, 2011).
The left arrow in Figure 1.1 is divided into the following three levels: the outermost circle (A), the middle circle (B) and the innermost circle (C), each representing a path for transferring inspiration from trend institutes, the contemporary society, entertainment business, point-of-sales data or whatever the source of inspiration is, to either new collections or replenishment orders.

The outermost circle (A) represents fashion companies that look to different fashion forecasting service providers for colour, style and material directions. Those directions are generally released 18 months prior to the selling season in order for chemicals suppliers to prepare new dye stuff for the fabrics, yarns and accessories and have it ready for the material fairs, which are generally 12 months prior to the selling season. After the material fairs such as Premièr Vision in Paris the fashion companies make the final collections and head out for selling the collections to fashion retailers. One of the biggest forums for this is Bread and Butter Berlin. Six months ahead of the selling season the production is started and after the quality is controlled the garments are distributed to the retailers. Typical for such supply chains are up-front buying and limited possibilities for replenishment buying (Davis-Burns and Bryant, 2005).

The middle circle (B) represents fashion companies that look to the trendsetters for inspiration. Trendsetters are the celebrities, music industry, fashion magazines and increasingly important fashion bloggers. The fast fashion company Zara is renowned for the “trend spotters” that work for them and collect inspiration from the trendy spots in the contemporary society (Ghemawat and Nueno, 2003). Parts of the inspiration may come from other design pieces that are often copied with pride. One Swedish company that is...
doing this is Gina Tricot; they explain their fashion like the following (Gina Tricot, 2010):

“Brand new fashion that reflects current trends”.

The innermost circle (C) represents fast fashion companies that by quick response manufacturing are able to quickly turn trends into products and deliver news every week to the customer or to replenish stockouts. Zara, once again, stands out as an example for fast replenishment (Ghemawat and Nueno, 2003) as well as Benetton that used point of sales data to dye raw white products (Mantle, 2000). Tailors and mass customisers are also included in this flow.

Fashion companies do not confess to one of the methods of gathering inspiration, but rather on several of them. For example, they use the trend institute for identifying the colour directions, study the trendsetters for models and then replenish accordingly. Exactly where each designer finds inspiration differs and most companies use a mix of the levels to prepare and replenish their collections.

**Right arrow**

It is not enough that a trend direction is interpreted by the fashion companies and turned into a collection. The customers have to be prepared to want the garments when they arrive in the store. That is where the marketing experts come in. Through media, movies and music they start working the customers to want new garments every season. The trend institute does not only predict what the colour and style direction will be for the years to come but they also identify key consumer issues for the next seasons. An example of this is taken from WGSN, in 2010 they predicted that the 2012 consumers will feel (Marshall-Johnson, 2010):

- A sense of triumph over adversity
- A new-found desire for beauty and developed style
- A need to creatively express themselves and a thirst for the fresh, unusual and surprising
- Renewed energy for an incredible future and acceptance for the “new”
- Positive an excited about the increased speed of change
- The need for a stable, organised base in the form of home, family and responsible society
- The desire to edit lighten up
- The need for filters in order to surround themselves with only exactly what they want
- The need for permission, often through technology, to start from scratch

Whether the customers will feel like this in 2012 is still to be determined, but the fashion companies and the trendsetters have started to prepare them for it.
Customers will be affected in different ways by the trendsetters and create certain demands, implicit or explicit, for certain products or services.

1.1.1 The gap

In Figure 1.1 the gap is found between the customer and the retailer and it illustrates the difference in what the customer desires and what is offered in the retail outlet. The problem is that the two arrows in Figure 1.1 are not aligned, they diverge into marketing and into production and different actors are operating the two sides. The arrow going left has its set of brains interpreting trends and style directions in its way and the one going right has it set on interpreting the same things but differently.

Supply chains usually involve a product part and a service part. The product is not worth anything unless there is a customer who is willing to pay for the product. To make it easier for customers to find the product and pay for it, it is usually presented in a physical outlet or on the Internet. The quality of a product and its characteristics are usually decided several months prior to the selling season and cannot be changed. The quality of the service is decided in the interaction between the customer and the service process. During the delivery of the product and service, gaps will appear and they can be illustrated as in Figure 1.4. Product is used as a term for service and product combined.

Figure 1.4 Service quality gap model in relation to fashion, modified from Harrison and van Hoek (2008).

Gap 1 refers to the difference between the customer expectations and how they have been translated into a product specification (Harrison and van Hoek, 2008). Generally in fashion, customers are not consulted when a collection is developed. Fashion companies rather look at trend directions, the contemporary society as a whole and point-of-sales data when developing new styles and collections. The most common reason for not consulting the customer is that “the customer does not know what she wants.” Or, like Henry Ford once said regarding the invention of the car (Quotations of Henry Ford, 2006):
“If I would have asked people what they wanted they would have said faster horses.”

Gap 2 is the difference between how the specification was drawn and the final product or service (Harrison and van Hoek, 2008). During the production process of a garment there are several opportunities for things to go wrong. To cope with the uncertainties, samples and counter samples are sent between suppliers and customers and very often styles are removed from the collection just because they do not fit the specification.

Gap 3 is the difference between how the customer expected the product to be and how she perceived it on delivery (Harrison and van Hoek, 2008). Fashion customers are notoriously unpredictable and shops very much on impulse (Cerruti and Harrison, 2006). Thus, there is not very much expectation built up around one particular garment. The expectation is rather on what the garment will do for the customer once it is bought, whether it is to protect her from the elements or show people at the next cocktail party what a unique sense of style she has. Or for that matter, how updated with the latest issues of Elle and Vogue she is.

Gap 4 refers to the difference between how supplier and customer experienced the product delivery (Harrison and van Hoek, 2008). One problem with the fashion customer is that she in general does not let the store staff know why she left the store empty handed. She might very well be satisfied with the offering in the store and plan to come back at another time to finalize the purchase; she might be in the store looking for her friend; or she could not find a garment that fit her preferences (Mattila et al., 2002).

The focus in this thesis is on gap 3 – the difference between how the product was expected to be and how the customer perceived it on delivery. Figure 1.5 illustrates the gap between the retailers offer and the customers preferences and some of the dynamics of the gap. Customers have a set of expectations regarding size, colour, model, fit, etc. when shopping for a garment. Expectations can be either high or low, and depending on the customer and on the type of garment the zone of tolerance will be different. Some customers have very high desires on fit but settle with an adequate service, while others may have very high desires regarding the brand of the garment. Different requirements on the delivery of a service creates complexity in the system and it is up to the company to identify the zone of tolerance for their customers (Parasuraman et al., 1991).
The are many reasons why a garment does not fulfil the expectations of the customer. The most usual include fit, form and function. According to WGSN (2002), an online trend analysis provider, 69 percent of women said that fit was the most important quality of a pair of jeans. Comfort was second at a distant 13 percent. Ten percent of the customers said style is the most important quality. Others such as Bickle (1995) and Shofield and LaBat (2005) confirm that a significant amount of customers have problems finding the right fit. Shim (Shim and Kotsiopulos, 1991) writes that big and tall men who regard clothes as an essential part of building their career also have difficulties finding fashionable garments that fit them.

According to Cerruti and Harrison (2006), the nature of the fashion market is in general characterized by short life cycles, high volatility in demand, low predictability and high impulse purchasing. These characteristics are reflected in the key performance indicators in many of these supply chains. Sell-through percentage in a traditional supply chain that operates mostly on up-front buying is around 66 percent and lost sales around 20 percent. For the more responsive supply chains that use a short term buying strategy or a replenishment strategy, sell-through percentages are higher, up to almost 92 percent. Lost sales are lower, nearly 5 percent (Mattila et al., 2002). In short, the key to better supply chain performance is to bring customers closer to production, maybe all the way to the design table. Mass customization is a concept that does exactly this – customers are allowed to configure or, if you will, cobine and mix their own products. The essence of mass customisation is to marry economies of scope with economies of scale, and to do it at a profit (Pine, 1993).

1.2 Focus topic: Mass Customization

In 1993 Joseph B. Pine II wrote the book *Mass Customization: The New Frontier in Business Competition* (Pine, 1993). He claimed a new manufacturing paradigm was evolving from the mass production era and the essence of it would be customer involvement. According to Duray (2002) the two identifiers for mass customisation is: 1) customer involvement in the design process; and 2) mass,
to gain scale volumes through modularity. Modularity keeps the number of options down and allows for repetitive manufacturing. By bringing the customer close to the company, actually all the way to the drawing table, a supply chain should, at least in theory, be able to respond fast and accurately to true customer demand. There are companies already that have successfully employed mass customisation. According to Da Silviera et al. (2001), there are a few key factors that are needed for successful mass customisation. For example, technology such as Internet connection has to be ready and available, the products have to be customisable and there has to be a market for the product. Common for the state of the art mass customisers is that they offer niche products that they operate online, thus facilitating the Long Tail economy where the idea is to sell less of more (Anderson, 2006).

1.2.1 State of the art

There are several mass customisers in business that has, very much because of the Internet, succeeded in mass customisation. They sell everything from drums to candy bars and it can all be “made your way.” An extensive list can be found at the website www.configure-database.com. It contains a list of mass customisers that offers a wide range of products. Here is a presentation of the pioneering and most commonly heard-of mass customisers today.

Figure 1.6 Tailorstore logotype (Tailorstore, 2011).

Tailorstore.com is a Swedish manufacturer of mass customised apparel with its head office in Sweden and manufacturing in Sri Lanka. Tailorstore started their business in 2003 under the name “Tailorshirt.com,” but later changed it to “Tailorstore.com” since they aimed to produce more than just customized shirts. Their current product range includes business and formal dress, casual shirts, underwear, chinos, shorts and polo shirts. Tailorstore.com is a pioneer on the mass customisation market and is still ahead of most of its competitors on user friendliness and service. Customers can choose from more than 200 types of fabrics in a price range from 30 to 90 € (Tailorstore, 2011).

Figure 1.7 Nike ID logotype (Nike, 2011).

Nike launched their online platform for customising sports shoes in the beginning of the 2000s. They were the first to offer customised shoes of any scale online. They further developed the concept to also include it in their Nike Town retail outlets where customers were offered assistance when customising their shoes. The price of a pair of mass customised Nikes is around 10 percent higher than a mass produced shoe and Nike now offers a wide range of
customisable running, soccer, baseball, fitness and casual shoes. They also offer customised watches, gym bags, shirts and accessories (Nike, 2011).

![Miadidas logotype](Adidas, 2011)

Adidas and Nike have similar customisation services; the customer is offered a wide range of customisation options on everything from shoes to gym bags. Adidas also offers individual fitting of the shoes. In addition to the customisation service, Adidas also offers a service called “Micoach®” and is a software that customises training programs for the user to reach their particular goals. Adidas is also visiting running events with their customisation service (Adidas, 2011).

![Mini logotype](Mini, 2011)

Car manufacturers were very early on offering different set ups of their vehicles to fit the individual needs or requirements from different customers. However, BMW-owned Mini was one of the first to offer more than three or four additional premium packages. Mini offered the customer to in more detail choose the colour on the housing of the rear mirrors, colour and design of the door handles, different roof graphics, matching of different materials and colours inside the car, etc. (Mini, 2011).

![Shima Seiki logotype](Shima-Seiki, 2011)

Shima Seiki is a Japanese manufacturer of knitting machines that also sells mass customised knitted garments. They were the first to offer customised knitwear in their Factory Boutique in Japan (Shima-Seiki, 2011). One of the simulations in this thesis builds on data from Shima Seiki.
1.2.2 Previous research: licentiate thesis

Prior to the doctoral thesis a licentiate thesis was written. It was presented in the fall of 2009 and presents the development of the Knit on Demand project, specifically. Here is the abstract of the licentiate thesis:

*One-piece fashion*

The fashion market is characterised by short life cycles, low predictability, and high impulse purchasing. In order to respond to these characteristics, companies are constantly introducing new collections and models. There are now so many new models introduced that the seasons have been erased and the leader of fast fashion, Zara, introduces 211 new models each week. Not all of these garments are sold at full price—the sell-through factor in fashion, which indicates how many of the total SKUs are sold at full price, is approximately 65 percent. One of the reasons why so much must be sold at a reduced price is that the fashion companies might have created a new buying behaviour among their customers by offering everything quickly. This new buying behaviour cannot be answered with traditional supply chain management.

Knit on Demand is a research project in the Swedish School of Textiles. The objective of the project is to demonstrate a production method for knitwear that may strongly influence the ability of the fashion industry to meet new demands for agility in customer relations. It will also provide insight and transparency in the total cost picture related to logistics and supply chain management, which leads to improved decision support in outsourcing and off-shoring strategies and may contribute to increased local fashion production. Knit on Demand differs from traditional garment manufacturing since nothing is produced to forecast and everything is produced to order from the end customer.

Together with Ivanhoe AB, a producer of knitwear, and SOMconcept, a tailored fashion retailer, the idea of on-demand knitting has developed into a business concept where the customer is allowed to design their own garments. The customer chooses his or her fit, colour and model, places an order, and one week later the garment is delivered. The customer is not completely free in his or her design because the quality and lead-times of the production processes have to be guaranteed. Therefore, the process is really more a configuration of pre-engineered modules.
The methods used are case studies with some action research as the researchers have taken an active role in the development of the project. Mass customisation as a concept and on-demand business have great potential to decrease wasteful overproduction of garments and benefit the customer, company and society: the customer receives a garment that better fits his or her needs, the company is able to meet customer demand more accurately and society does not have to pay for overproduction.

Keywords: Fashion logistics, Mass customisation, Demand driven supply chain management, Knitwear, Demand chain management, Agility.

Four papers were included in the licentiate thesis, two of them are also included in the doctoral thesis since they explain the initial phases of the project.

Paper I, included in the doctoral thesis

Paper II

Paper III, included in the doctoral thesis

Paper IV
1.3 Focus case: Knit on Demand

Knit on Demand is a research project at the Swedish School of Textiles in collaboration with a knitwear producer in the south of Sweden, Ivanhoe AB and a retailer of tailored fashion in Stockholm, SOMconcept AB. The purpose of the project was to develop and test a new production and logistic solution for agility in customer relations.

Initially, the idea was to build a store inside the knitting company’s facilities and equip it with a complete garment knitting machine, a digital design system connected to the knitting machine and a design technician. The concept store was called “Knit in Shop” and the idea was that customers could come into the store, sit down with a design technician, and, with the help of a digital design system, create a personalized knitted garment. Figure 1.11 illustrates the set up of the store.

![Figure 1.11 Illustration of the Knit in Shop model.](image)

When the customer was happy with the design and the technician had guaranteed the garment’s manufacturability, it would be instantly produced on the Complete Garment machine and three hours later it would be ready for delivery. Meanwhile, the customers could go to other stores in the area and do some shopping or have a cup of coffee or something to eat.

In the end the solution appeared quite differently. Instead of a store in Gällstad, with a Complete Garment knitting machine and a digitalized customisation system, the garments were sold in the department store PUB Huset (figure 1.12) in Stockholm by the fashion retailer SOMconcept AB and there were no fancy digital tools. Ivanhoe AB was still the producer but there was no knitting machine in the store and the order fulfilment lead-time was
significantly longer than the originally intended three hours. The distance from Stockholm to Gällstad and the fact that the design system and knitting machine was everything but seamlessly integrated increased the lead-time to between one and three weeks.

Figure 1.12 PUB Huset department store in Stockholm.

In the SOMconcept store other customisable products are also sold such as belts, jackets, suits and pants. Figure 1.13 illustrates the selection of jackets, vests, pants, threads and contrasting fabrics.
The knitwear and the pant sizes are based on standard sizes. Knitwear is based on a SOMconcept preferred medium silhouette, which has then been graded to standard size extra small to extra extra large. The pants are similarly based on standard pant sizes.

1.3.1 Researchers in the project

There are three researchers involved in the Knit on Demand project, each with different tasks.

- **Jonas Larsson** – Author of the thesis with a focus on developing the supply chain part of the Knit on Demand concept.
- **Pia Mouwitz** – Researcher with responsibility for the design of the garments.
- **Joel Peterson** – Researcher with responsibility for technology development.

Even though the different researchers each had a different focus, the tasks and responsibilities merged together and the focus of the research became to get the show on the road.

1.4 Additional cases

In addition to the Knit on Demand project, two other cases, Shima Seiki custom made and SOMconcept’s pants, were researched between 2006 and 2011.

**Shima Seiki custom made**

In 1995 Shima Seiki introduced the first knitting machine capable of producing a complete ready-made flat knitted garment. The company called their complete garment concept WholeGarment®. In the same year Wajima Kohsan Ltd. opened the first Factory Boutique Shima, a retail store specialising in on-demand production of customised knitted garments, in Wakayama, Japan. Factory Boutique Shima is a business concept that combines knitting technology and mass customisation on the retail level and it has similarities with the Knit on Demand project. The purpose of the Shima Seiki project was to analyse and compare two customisation concepts. One manual system and
one digital configuration system. Both systems are developed by the Japanese knitting machine manufacturer Shima Seiki.

**SOMconcept’s pants**

SOMconcept started as a retailer and manufacturer of tailored fashion in 2006 with a focus on pants such as slacks, jeans and chinos. Pants are the bread and butter of SOMconcept and demand is high. One case study of how customers choose to customise jeans, chinos and slacks has been conducted. The purpose was to explore differences in customisation between different types of pants and associations between different types of customisation.

1.5 Delimitations

This dissertation presents three cases. First, the Knit on Demand project, from the development of design solution to the end consumer, what the challenges are and the end result. In addition to the Knit on Demand project, it also presents two other studies: one on SOMconcept’s mass customised pants and one on the Japanese knitting machine manufacturer Shima Seiki, which has a similar set up of a mass customisation business in Japan. Figure 1.14 illustrates the delimitations of the thesis, which is the process of translating true customer demand into a finished garment.

![Figure 1.14 Focus of the thesis.](image)

It is the inner circle that is the focus of the thesis, the transformation of true customer demand into a mass customised garment and the related processes such as manufacturing and information flows.
1.6 Purpose and research questions

The discussions of the problems and concepts above indicate that there is a need for a mass customisation business model in the fashion business, one that is more responsive to customer demands. The original purpose of the Knit on Demand project was to develop and test a new production and logistic solution for agility in customer relations.

The idea was that by offering mass customised garments, customers would be more satisfied with their garments, there would be less garments on sale and the gap between what the customer expects and what is offered by the retailer would decrease. To test this, a supply chain for knitted mass customised garments were set up and other similar concepts were analysed. Based on this, I, the author of the thesis pose the following overall research question:

*How does a responsive supply chain for mass customised garments work?*

The above question is rather ambitious and the aim of the thesis is contribute to the further development of fashion business and learn how companies can be more responsive to what customers demand. This is done by developing the Knit on Demand business concept, test it in a real business environment and analyse additional similar cases. The real business environment gives opportunities to explore how the supply chain works in reality and what the true problems are.

The purpose of the research presented in here can be broken down and analysed into four research questions, each of them guided by the aforementioned overall research question. The first one deals with the customer, the second one with supply chain management, the third with production and the fourth with design. Figure 1.15 illustrates where in the model each of the research questions (RQ) fit.

![Figure 1.15 Research question’s fit in model.](image-url)
Customers, research question 1

Every supply chain starts with the customer, since they are the ones putting money into the system. Customers have explicit and implicit demands regarding garments, design options and shopping experiences. Fit, or the lack of fit, is the single largest issue for customers when it comes to customer satisfaction (Bickle et al., 1995, Kwong, 2004, WGSN.com, 2002). On average, big and tall men are more dissatisfied with the service at the retailer and especially with fit (Shim and Kotliopulos, 1991). The customer involvement is an essential part of mass customisation (Duray, 2002), but with a lot of choice comes the risk that customers become confused and walk out of the store empty handed (Huffman and Kahn, 1998). Research question 1 aims to analyse what is needed in order to satisfy the customer when he or she purchases a customised garment:

*What components are necessary for the customers to purchase customised garments?*

Supply chain processes and risk, research question 2

One part of the original purpose was to develop a logistic solution for agility in customer relations. Zara and Benetton were pioneers in agile fashion supply chain management (Christopher et al., 2004). By cutting lead-times and postponing certain value adding processes to a decoupling point in the supply chain where demand is more certain these companies are able to reduce uncertainties and answer much better to customer demand, increase sell-through percentage and decrease lost sales (Ghemawat and Nueno, 2003, Mantle, 2000, Manuj and Mentzer, 2008). An extension of Zara’s and Benetton’s business concept would be to also involve the customer in the design of the garments. Mass customisation does this and is also built very much around postponement of value adding processes to the customer order decoupling point (Rudberg and Wikner, 2004). By understanding the processes, their relation to the decoupling point, how much they cost and their lead-times, it is possible to further develop supply chain processes to produce less waste and answer better to true customer demand. Research question 2 addresses the understanding of the processes in a supply chain for mass customised garments:

*How do the processes in a supply chain for mass customised garments work?*

Technology, research question 3

One part of the purpose of the Knit on Demand project was to develop a production solution that includes a knitting machine, sewing machines and a design system. According to Franke and Piller (2002), the following three things are needed for a sucessful design system: 1) the core configuration software that the customer uses to customise the garments; 2) a feedback tool that visualizes the choices the customer has made; and 3) the analysis tool that translates the choices into a production order. In addition to the configuration tool, a flexible manufacturing system is needed (Pine et al., 1993). Complete
Garment technology has the flexibility and speed needed (Choi and Powell, 2005), but it is expensive. Therefore, a technical solution where the ideas from the Complete Garment system is applied to the existing manufacturing equipment was developed, leading to research question 3:

*What technical solutions are necessary to produce and sell customised garments?*

**Design, research question 4**

Design for mass customised garments differ a little bit from design of regular garments. For example, the design has to be flexible enough to cater to a wider range of body types than the standard sizes include and at the same time ensure manufacturability. The aim of mass customisation is to provide customer satisfaction through a greater variety of products. According to Tseng and Jiao (1996), the key to successful design is optimizing commonality, creating a product family architecture and integration of the customer, logistics, marketing and sales. Commonality in design is essential since mass customisation systems have decreased productivity than mass production systems, which inevitably leads to higher prices (Alvan and Aydin, 2009). Research question 4 analyses how the design of the garments can be further improved for better commonality, product architecture and integration:

*How can the design of mass customised garments be improved?*

1.7 Thesis outline

Chapter one, *Introduction*, introduces the reader to the fashion business in general and to why the thesis is written by presenting the background to the related problems in the fashion industry. It aims to narrow the scope of the fashion business in general down to the Knit on Demand project, which is the focus of the thesis and also to the additional researched cases. State of the art examples of similar projects are also presented in order to familiarise the reader with the researched area.

Chapter two, *Theoretical framework*, presents the relevant theories for the thesis. The theories will later be used to answer the research questions stated in chapter one and build credibility for the conclusion.

Chapter three, *Method*, introduces the reader to how the research in the thesis was conducted. What methods have been used to collect data and how the data was transferred into information. It also elaborates on the abductive approach in relation to the time line of the thesis and the challenges with the chosen methods.

Chapter four, *Summary of results*, presents a summary of the included papers and of the individual studies. In the end of the chapter the interconnections between the papers are presented.

Chapter five, *Analysis*, compares the results of the papers in relation to each other and to the theoretical framework in order to find answers to the research questions.
Chapter six, *Discussion*, discusses the answers to the research questions in relation to the fashion business in general.

Chapter seven, *Conclusions and further research*, concludes the thesis and suggests what will be the next step in research.
2 Theoretical framework

This chapter presents the relevant theories for the thesis. The theories will later be used to answer the research questions stated in chapter one and build credibility for the conclusion.

2.1 Supply chain management

The overall topic of the thesis is supply chain management and more specifically supply chain processes. According to the Council of Supply Chain Management Professionals (CSCMP), the definition of supply chain management is the following (CSCMP, 2011):

“Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers and customers. In essence, supply chain management integrates supply and demand management within and across companies”.

I have chosen the definition from CSCMP since it includes the customer and because it integrates supply and demand management.

The title of the thesis, Development and testing of a responsive supply chain for mass customised garments, suggests that the supply chain operates on customer demand. In a truly demand driven supply chain nothing would happen unless there is a customer order. However, the lead-time to perform all the activities in a supply chain, such as material order, shipment of material to warehouse may be too long so usually many of the activities, except the final configuration of the products, is done in advance. In a supply chain for mass customised garments the final configuration takes place after the decoupling point. The decoupling point is the point where a decision regarding form and/or quantity is made. In demand driven supply chains it is sometimes called the customer order decoupling point (CODP) (Rudberg and Wikner, 2004). In a supply chain there are many decoupling points and its place differs depending on the set up of the supply chain and the products it produces.

There are basically three main strategies for where to put the decoupling point: Make to stock (MTS), assemble to order (ATO), make to order (MTO) and engineer to order (ETO). Make to stock is typically used in fashion and apparel manufacturing and most other commodity industries where shelf availability is an order winner (Harrison and van Hoek, 2008). Production volumes could be decided either quantitatively using statistics from, e.g., sales, qualitatively making qualified guesses on what will be sold or a mixture of the two. Assemble to order moves the decoupling point upstreams to the stage where products are assembled from a set of pre-engineered modules. Further downstream there is make to order where products have a higher degree of customer specific design (Harrison and van Hoek, 2008). Engineer to order includes the customer already at the drawing board (Rudberg and Wikner,
Similar to haute couture garments, Figure 2.1 illustrates a make to order supply chain from a decoupling point perspective.

![Diagram of CODP in a MTO supply chain](image)

**Figure 2.1 CODP in a MTO supply chain, modified from Christopher and Towill (2001).**

Upstreams from the decoupling point, where demand is unknown, focus to produce modules or parts with high commonality, scalability and modularity and to postpone the assembly of parts and modules to when demand is more clear (Huang et al., 2005). It is also useful to allocate production capacity in order to meet the due dates of production (Dean et al., 2009). At the decoupling point the customer’s order is visible and material and production resources are attached to a customer order. Christopher and Towill (2001) explain the differences between upstream and downstream characteristics in terms of lean and agile where lean in this case means an efficient supply chain that focuses on reducing cost; and agile means a flexible supply chain that focuses on offering the customer a variety of products. Note that while lean and agile are not identical, synonymous or interchangeable, they both do emphasise the importance of developing manufacturing capabilities and the reduction of wasteful activities (Brown and Bessant, 2003).

### 2.1.1 Measuring the success of a fashion supply chain

Like any business the fashion business has its set of success factors and performance measures. These have been developed in order to control the supply chain and with the ultimate target to decrease the gap between customers and the retail offer. Mattila (2002) suggests critical success factors for a fashion supply chain, these are: forecast accuracy, process lead-time, offshore/local sourcing mix and up-front/replenishment buying mix. The forecast accuracy is critical since buying decisions in many cases are taken months in advance of the selling season. The total forecast error is a combination of assortment error and volume error (Mattila et al., 2002). Forecast accuracy is dependent on process lead-times (Harrison and van Hoek, 2008), the further away from the customer the higher the forecast error. Process lead-times are in turn dependent on the offshore/local sourcing mix, that is the volume that is produced offshore to benefit from low production cost compared to the volume produced locally to benefit from quick response capabilities. That is in turn dependent on the up-front/replenishment buying mix where it is decided how much should be bought and produced prior to the season and how much should be...
bought and produced in season. To measure the success of these factors there is a set of performance measures for seasonal fashion, these are: lost sales, service level, sell-through percentage, gross margin, stock turn, GMROI and product substitute percentage. This thesis focuses more on lost sales, service level and sell-through percentage, which is explained below (Mattila et al., 2002):

\[
\text{Lost sales} = \frac{\text{No. of customers finding the SKU of their preference}}{\text{No. of visitors in the store}}
\]

Lost sales indicate how well the inventory corresponds with actual demand. As a measure it is useful when planning the season, but not in retrospect due to complex buying behaviour. It is not possible to ask each customer why they entered a store, why they left or why they purchased a particular item.

\[
\text{Service level } t = \frac{\text{No. of SKUs available in week 0}}{\text{No. of SKUs available in period } t}
\]

Service level is useful for measuring the availability of SKUs during the season. During the season the service level will decrease unless stock is replenished.

\[
\text{Sell-through percentage} = \frac{\text{SKUs sold at full price}}{\text{SKUs sold in total}}
\]

Sell through percentage indicate the forecast error, how well the forecast corresponded to actual demand.

### 2.2 Mass customisation


“…creating variety and customization through flexibility and responsiveness.”

Products are customisable in different ways, either the presentation of the product is changed or the functionality of the product is changed. Gilmore and Pine (1997) present four faces of mass customised products (Figure 2.2).
Figure 2.2 Four faces of mass customisation, modified from Gilmore and Pine (1997).

Lego is a form of *adaptive* customisation where the manufacturing company makes no customer specific changes at all to the product, either in the products’ functionality or in its presentation. It is the simplest form of customisation and assembly of the modules are done by the customer. *Cosmetic* customisation is when a standard product is given a customised appearance that is specific for one customer, but there is no change in the functionality of the product. *Transparent* customisation is the change of the functionality of a product but not the appearance, an example of a product is prescription glasses. The strength of the glasses are individually customised for each customer but the design of the glasses are not. *Collaborative* customisation is probably what most people would consider true customisation. Both the functionality and the presentation of the product is changed. When customising a shirt for example, the customer changes the look of the garment and has it made to measure.

### 2.2.1 Success factors of mass customisation systems

According to Da Silveira et al. (2001), the success of a mass customisation system, as any other system, depends on internal and external factors, but the following factors are the specific ones for mass customisation systems:

- **Customer demand for variety and customisation must exist** – the success of the system depends on the balance between the sacrifice customers make for mass customised products (waiting time, configuration process) in relation to delivery performance and expected delivery performance.
- **Market conditions must be appropriate** – For mass customisation concepts to gain sufficient volumes facilitating the Internet is necessary. Levi set up a mass customisation concept in 1994 called the “Personal Pair.” It was initially a success, but customers had to visit the stores and that became a nuisance for the customers (Yeung et al., 2010).
- **The value chain should be ready** – There must be suppliers, distributors and retailers ready and willing to attend to the customer’s demand. The supply chain’s information systems also have to be efficiently linked.
together. Brown and Bessant (2003) points out the importance of manufacturing strategies when pursuing mass customisation in an organisation.

- **Technology must be available** – There has to be appropriate manufacturing technology available in the supply chain (Da Silveira et al., 2001). Pine et al. (1993) claim that mass customisation systems are one of the best opportunities offered to coordinate the implementation of advanced manufacturing technologies.

- **Products should be customisable** – Products should be designed so that they consist of independent and pre-engineered modules that can be efficiently assembled into different products and final assembly of the product is postponed to the very last stages of the order fulfilment process (Feitzinger and Lee, 1996). Successful mass customisation products have high levels of commonality, scalability, postponement and modularity (Huang et al., 2005). It enables lower production costs compared to fully customized products. Rapid prototyping is also needed due to the short life cycles of mass customised products (Da Silveira et al., 2001).

- **Knowledge must be shared** – Mass customisation strategies depend on the ability to translate dynamic customer demand into products and services. Companies that pursue mass customisation must emphasize a knowledge creation culture and distribution of knowledge in the supply chain (Da Silveira et al., 2001).

2.3 The Long Tail economy

Chris Anderson, the chief editor of *Wired*, coined the term “Long Tail economy” in 2006 (Anderson, 2006). It first became evident in the music and movie business where people no longer bought records and DVDs in the stores but instead downloaded – legally or illegally – tracks and movies via the Internet. Figure 2.3 describes the Long Tail economy with the hits in the head of the curve and the niche products in the tail. Most people are able to find garments that fit their preferences right off the shelf and are able to buy what is in the head of the long tail (Figure 2.3). However, a few people have difficulties in finding their size and have to look further down the tail.
Mass customisation is still a niche concept and will continue to be so in the next future. Mass customisation fits very well into a description of business concepts that could flourish in the Long Tail economy.

There are three forces (Figure 2.4) that drive demand down the long tail of products. The number one enabler for the Long Tail economy is the spread of the Internet and rapid increase in bandwidth. Access to the Internet and increasing bandwidth has resulted in the costs of distribution falling dramatically and a local garage band has as much opportunity to reach the market as Sony/BMG (Anderson, 2006). Ninety percent of Swedes between 16-74 years of age were connected to the Internet in 2010 (Statistics Sweden, 2010).

- The first force is democratization of the production tools. Everybody with a PC and Internet connection can make their own music or movie using cheap or free music or video editing software. As an example, mass customisers have their configuration tools, which allows customers to customise products for free.
- The second force is the democratization of distribution. Distribution in the online world is free. It does not cost anything to upload music to Myspace.com or YouTube. It has very recently become cheap to have a store for physical products on the Internet as well. Several companies...
offer Web shops with secure payment services for as little as 100 euros per month.

- The third force is the connection of supply and demand. By different filters that drive the demand down, the tail supply and demand is connected. Fashion blogs and online advertisement are examples of how the connection of supply and demand happens in the online fashion world.

The democratization of the means of distribution and connection of supply and demand have been most important for the fashion industry. Pre-Internet, a new company would have had a hard time selling their goods to anyone other than the people in the same town or their closest friends, unless they promoted themselves at a fashion fair or went on a selling trip to fashion stores, which is very expensive. Instead, in the online age, the designer trades a couple of garments for a few lines of text and a picture in a well renowned blog and suddenly he or she reaches several hundred thousand potential customers that are interested in fashion (Anderson, 2006).

2.4 Customers

Every supply chain starts and ends with the customer since he or she is the one putting money into the system. Authenticity and the shopping experience is a critical factor for attracting the “new consumer.” The new consumer is described as being involved, individualistic, well-informed, independent and is seeking authenticity rather than convenience in most of her major purchases (Lewis and Bridger, 2000). Research question 2 addresses the customers’ behaviour and what components are necessary for the customers to purchase customised garments.

2.4.1 Choice and mass confusion

Dellaert and Stremerch (2005) conclude that mass customisation can strengthen a brand as long as the steps in the design process are easily understood by the customer. In this process the customer chooses from a set of pre-engineered modules. When all the modules are chosen, the garment is ordered, produced and delivered to the customer.

One challenge for both the customer and the company in selling mass customised products is that the customer has to remember the choices throughout the design process while combining it with more choices to build their garment. During the design process the customer creates an image of the garment, an image that she keeps and might adjust until the final delivery. It is the company’s challenge to make sure that the image of the garment that the customer creates is as equal as possible to the ordered garment once it is ready. When the company succeeds, their customers will be happy; if they do not succeed, the customer might reject the garment. It is notable that Swedish consumer laws state that if a customer has specified the product and the supplier has made it according to the specifications, the customer has no right to return it (Konsumentverket, 1990).
Generally, papers that are written about configuration tools suggest that there should be a digital product configurator involved in the process (Piller et al., 2003, Franke and Piller, 2002, Cross et al., 2009, Andersson et al., 2007). If the customer is confused by a wide assortment, it might be due to perceived complexity and not the actual complexity (Huffman and Kahn, 1998).

Depending on the customers and their tolerance of ambiguity (Furnham and Ribchester, 1995), they will either feel comfortable or insecure in the design process. The insecure feeling is generally referred to as mass confusion (Piller et al., 2005). For the customer with a low tolerance for ambiguity it would be convenient to have a visual feedback tool that helps the customer remember the choices. Schwartz (2004) claims in his book, The Paradox of Choice: Why More is Less, that too many choices in the offline world confuses the customer and leads to lost sales. He also suggests that the same applies to the online world. Chris Anderson (2006), on the other hand, claims in his book, The Long Tail Economy: Why the Future of Business Is Selling Less of More, that it is simply a question of how the options are presented that makes choice good or bad. Huffman and Kahn (1998) have analysed how people react to variety and how variety is best managed. They conclude that it is the company's task to educate the customer on the variety, and they can do so in basically two ways: attribute-based presentation or alternative-based presentation. Most people prefer the attribute-based presentation where the customer explains how the product should be configured; then the product is chosen from a large assortment by the shop assistant and presented to the customer. In the alternative-based presentation the customer is presented to all the alternatives and configures the product. Interestingly, customers are equally satisfied with the end result from both methods. This conclusion is also supported by Kurinawan et al. (2006). Huffman and Kahn (1998) also conclude that when companies fail to educate the customers about the alternatives, the customers may delay purchasing or leave empty-handed in a state of "mass confusion." This is also supported by Boyd and Bahn (2009). The same authors demonstrate that if an assortment is well presented, customers prefer a large variety of products. The production manager in the Knit on Demand project concludes the discussion on whether choice is good or not:

"You cannot sell the black one if you don't have the turquoise one" - Ulf Göthager, Ivanhoe AB

2.4.2 Customer experience and authenticity

Gilmore and Pine (2007) and Lewis and Bridger (2000) claim that the shopping experience and the authenticity of a concept or brand are becoming increasingly important for customers. Customers use all five senses when they are shopping: sense, sight, hearing, touch and taste. The more senses that are engaged while shopping, then the more memorable the experience. Gentile et al. (2007) define the customer experience as follows:
"The customer experience originates from a set of interactions between a customer and a product, a company or part of its organization, which provoke a reaction. This experience is strictly personal and implies the customers' involvement at different levels (rational, emotional, sensorial, physical, and spiritual)."

Gilmore and Pine (2007) write that customers are increasingly shopping not for a specific product but for an experience, and they want this experience to be authentic. It is the rise of the creative class, even though they do not want to be called a class since most of them are individualists that value creativity, individuality, difference and merit (Florida, 2002). These customers want their shopping experience to be real, and they want it from transparent sources so that the product is guaranteed to be authentic. This is not the kind of authenticity offered by slick marketing experts (Gilmore and Pine, 2007). One way for a business to create authenticity is to blur the boundaries between what is authentic, what is not and to create a story around a product or a service (Lewis and Bridger, 2000). “Design your own” is frequently used when a mass customiser is marketing their business concept to make the customer believe that the design actually is unique and personal when in reality the customer is assembling pre-engineered modules.

Gilmore and Pine (1998) also suggest that people are willing to pay more for poor service as long as the experience is worth it. One example is the Karaoke taxis in which customers pay for making that extra turn around the block just so that they can sing one more tune. They arrive later at the venue, with less money in their pocket, but they are still more satisfied than if they had taken a regular taxi. This partly explains why the customers in the Knit on Demand project who do not really need to buy made-to-measure garments are still willing to wait longer and pay a higher price for a product that most of them could buy off the shelf; they want the experience of designing their own unique garment.

There are four realms of an experience on two axes (Figure 2.5). One axis concerns the involvement in the experience, either the customer is watching an event as it takes place or the person is a part of the event. The second axis concerns how active somebody is in an event. A person may be passively participating in the event or actively participating, thus affecting the outcome of an event.
Experiences can be entertaining, educational, escapist or esthetical. An entertaining event tends to involve more passive watching as the event goes by, such as a movie or a theatre. An educational event requires a higher level of involvement from the customer, e.g., a ski lesson; the escapist experience requires active involvement from the customer such as playing in an orchestra or designing a garment. The esthetical experience is as immersive as the escapist experience, but it does not require the customer to perform an activity (Pine and Gilmore, 1998).

2.5 Supply chain processes and risk

One part of the purpose with the Knit on Demand project was to develop a production and logistic solution for agility in customer relations and the additional projects also have elements of optimising the supply chain. Agility is a concept that is widely used to describe supply chains and it is sometimes heard in the same context as lean manufacturing. Research question 2 aims to analyse how the processes in a supply chain for mass customised garments work and describe its characteristics.

2.5.1 Lean and agile

There are theoretical similarities between mass customisation, lean and agility. They all build on concepts that focus on the customer, integration of processes and waste reduction.

In literature there are two supply chain strategies that are very often mentioned: lean supply chain management and agile supply chain management. The focus of lean supply chain management is waste reduction and the creation of continuous flow. The focus of agile supply chains is to use market knowledge to profit from unpredictable and volatile marketplaces (Mason-Jones et al., 2000a). There are also combinations of both lean and agile that are referred to as leagile.
Fisher (Fisher, 1997) divides products into functional and innovative products. Functional products are commodities such as soap and basic food that have a steady and continuous flow to the market, so lean strategies suit them well. Innovative products, such as fashion garments, are products with high sales peaks and short life cycles that need a more agile supply chain (Figure 2.6).

<table>
<thead>
<tr>
<th>Efficient supply chain</th>
<th>Responsive supply chain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mismatch</td>
<td>Agile</td>
</tr>
<tr>
<td>Lean</td>
<td>Mismatch</td>
</tr>
</tbody>
</table>

Commodity products | Innovative products

Figure 2.6 What is the right supply chain for your product? (Fisher, 1997)

2.5.2 Lean production

Lean production originally comes from the philosophies of the Toyota Production Systems. The essence of lean production is not chasing seconds in manufacturing operations but to chase weeks in wasteful activities such as imbalances between work stations or excess inventory. The problem is not the time it takes to source material, convert the material into products and move them to the final customer; rather, the problem is the time between those steps when nothing is done to the product. This is normally referred to as “non-value adding time” or waste. The non-value adding time that accounts for a very large proportion of the total lead-time can be allocated very often to non-value adding activities that are referred to as the eight kinds of waste (Liker, 2004):

1. Overproduction - Producing items for which there are no orders or no use. It causes waste in storage and transportation plus the negative environmental impact from growing the cotton and dyeing the fabrics, for example.
2. Waiting - Workers waiting for material to arrive at the working station, tools to be ready, information on what to be produced or on the next production step.
3. Unnecessary transport or conveyance - Moving work in progress around the factory and in and out of storage.
4. Over processing or incorrect processing - Unnecessary processing due to poor tools or bad product design. Waste is also generated if the quality of the product is higher than necessary.
5. Excess inventory - Excess inventory causes longer lead-times, obsolescence, damaged goods, higher transportation costs and delays.
It also hides delivery problems, quality problems, production imbalances and production problems such as long lead-times and long set up times.

6. **Unnecessary movement** - When the operator has to move in wasteful ways such as looking or reaching for tools or walking.

7. **Defects** - Causes rework and replacement production and requires inspectors, which means wasteful handling time.

8. **Unused employee creativity** - Employees that are working in production possess valuable knowledge about processes. Time, skills and ideas might be lost if they are not engaged in production development.

Figure 2.7 illustrates a set up of a traditional fashion supply chain and production lead-times compared to non-value added activities and the corresponding lead-times.

![Figure 2.7](image)

**Figure 2.7 Production lead-times compared to total lead-time (Larsson and Peterson, 2008)**

From a “value added” perspective, traditional supply chains for fashion garments include mostly non-value adding activities. The value adding time only constitutes 0.0004 percent of the total lead-time. However, it is not possible to calculate strictly value adding activities and non-value adding activities since these are merging into each other creating semi-value adding activities.

### 2.5.3 The agile supply chain

The idea of the agile supply chain comes from the need to respond quickly to customer demand and is a result of characteristics of the fashion markets (Christopher et al., 2004). The definition of an agile supply chain could be (Christopher, 2000):

“Agility is a business wide capability that embraces organizational structures, information systems, logistic processes and, in particular, mindsets... Agile organizations have the ability to respond rapidly to changes in demand, both in variability and volume”.

An agile supply chain is market sensitive and operates best in unpredictable environments where variability is high, volumes are low and availability rather than cost is the order winner (Christopher & Towill, 2001). The agile organisation benefits from a volatile marketplace by understanding its
mechanisms (Mason-Jones & Towill, 1999). Leading fashion companies have learned to live with the volatility and are able to respond to and profit from it. The method most of them use is an increased number of collections each year to respond to the shifting demand of their customers.

An agile supply chain also requires integration in the supply chain to function properly (Bruce & Daly, 2006). Often, collaboration is needed to ensure high quality of products, services and delivery. Figure 2.8 illustrates the agile supply chain and its attributes. An agile supply chain is market sensitive and capable of reading and responding to true demand. The agile supply chain should not be viewed as a chain but rather a network that works toward a common goal. A characteristic of the network is the process integration that creates synergy for all the partners. The integration of the processes has its basis in the sharing of true demand information and it creates a virtual supply chain that is information-based rather than inventory-based (Harrison & van Hoek, 2008).

Figure 2.8 The agile supply chain (Harrison and van Hoek, 2008).

2.5.4 Marrying lean and agile

It is easy to be fooled that some kind of opposite relation exists between lean and agile, that they are in contrast with each other. That is not the case; lean philosophies focus more on reducing wasteful activities whereas agility focuses more on reacting on the market's movements. The concept of mass customisation has some of these elements. By not producing to forecast wasteful production is removed. Mattila et al. (Mattila et al., 2002) wrote that only 65 percent of the fashion that is produced is sold at full price, that means that 35 percent has to be marked down at the end of the season. From a lean perspective it would be considered very wasteful to have one third of the workforce manufacturing products that no customer is willing to pay full price for. Moreover, since the customer designs the products the supply chain is more responsive to the changes in the market place (Christopher, 2000). Thus it can be stated that a supply chain for mass customised products is both lean and agile, or as Mason-Jones et al. (2000b) would call it: leagile.
Supply chains for mass customised products basically work on make to order principles. They build on flexibility and the customisation of products to meet individual needs of the customers. Orders are received before the design and production is not initiated before there is an order (Kingsman et al., 1996, Gupta and Benjafaar, 2004). Usually mass customised products build on pre-engineered modules so that manufacturability and quality is guaranteed. Benetton uses a type of module based set-up where raw white garments are knitted and dyeing is delayed until true demand is better known (Mantle, 2000). However, postponement carries costs – extra material when variance is offered by more material and accessories, extra processing steps, less efficient processing steps and use of special production equipment (Gupta and Benjafaar, 2004). Gupta and Benjafaar (2004) also conclude that a postponement strategy is more desirable if there is slack capacity in the system. Moreover, make to order supply chains may benefit from increased information sharing and coordination (Sahin and Robinson, 2005).

2.5.5 Supply chain risk management

There are always arguments about what is risk and what is not. Kaplan (1997) wrote that:

"...maybe it's better not to define risk. Let each author define it in his own way, only please each should explain clearly what it is."

There are many ways to reduce risk; one is by including the customer in the production process since the risk of manufacturing would theoretically decrease. Thus, mass customisation can be seen as a way of risk management. Harland et al. (2003) wrote that risks usually incorporate some kind of loss – either financial loss, performance loss, physical loss, psychological loss, social loss or time loss. A loss is generally quantified to damages or prison sentences. It makes sense that the word risk is used in a negative sense even if the International Standard Organisation has defined it as an effect of uncertainty on objectives (Purdy, 2010). For the purpose of this thesis it makes sense to put risk management in a supply chain perspective. Jüttner (2005) defines supply chain risk management as the:

“...identification and management of risks for the supply chain, through a coordinated approach amongst supply chain members, to reduce supply chain vulnerability as a whole.”

All risks cannot be avoided completely so it is important to plan for those situations where there is a potential risk. Mitigation means to reduce the severity, seriousness or painfulness of an event. Manuj and Mentzer (2008) put risk mitigation in a pro-active sense. They suggest a number of strategies and mitigation plans to be used prophylactic to reduce the consequences of a disruptive event.
• Avoidance – used when a risk is considered unacceptable. Companies pull out of a market that is too risky or only compete in low-risk markets. One example is fashion mail-order companies that hinder the customers from buying more than one size and in that way reduces the risk of returns and ironically the chance of a purchase.

• Postponement – delaying the commitment of resources and material in order to maintain flexibility in production and capital. Postponement includes pricing, labelling, manufacturing, assembly, etc. The ultimate goal is to postpone as many order-fulfilment activities until there is an actual customer order. A pure form of postponement is mass customisation where nothing is produced until there is a customer order (Feitzinger and Lee, 1996).

• Speculation – decisions are made on anticipated customer demand. The opposite of postponement. Concept driven fashion brands or brands with low visibility in their supply chain usually use this strategy.

• Hedging – by having a globally dispersed portfolio of suppliers, customers and facilities, a local single, disruptive event is less likely to affect the whole supply chain.

• Control – vertically integrating business processes gain control of its supply chain but it is also less flexible. Zara is well known for their vertically integrated business model that gives them control of their supply chain (Ghemawat, 2003).

• Transferring/sharing risk – this can be achieved through outsourcing business processes to other organisations or by sharing profits and losses.

• Security – movement of nuclear, chemical and biological elements need a high level of security that is able to identify and focus on suspicious elements.

None of these strategies and plans is used on their own but rather in combination with each other. Postponement is for example widely used in fashion supply chains but not until after the decoupling point (Cerruti and Harrison, 2006). Before the decoupling point the speculative risk mitigation strategy is used. The most popular and very often referred to example is Benetton that produces raw white garments and dyes them closer to the customer order point where demand is more certain (Dapiran, 1992). One closely related example to Benetton is the Quick Response movement that started in the U.S. apparel industry in the end of the 1980s (Christopher and Towill, 2002). It is another example of risk mitigation even though it does not explicitly focus on risk. The Swedish telecommunication company Ericsson should perhaps have included hedging in their risk mitigation strategy portfolio prior to the 18th of March 2000 when a small fire in a small production cell at a supplier in Albuquerque, New Mexico stopped production of radio chips for three weeks and ended up costing Ericsson $400 million (Norrman and Jansson, 2003).

There are a few challenges for supply chains dealing with mass customisation. According to Ahlström and Westbrook (1999), the challenges
are: 1) increased material costs; 2) increased manufacturing costs; and 3) fewer on-time deliveries. Pine et al. (1993) writes that one of the reasons Toyota failed when they pursued mass customisation was that they kept the infrastructure of continuous improvement. Managers did not realize the problems were caused by failure to transform the organisation from an organisation of continuous improvement to one that could also handle mass customisation.

2.6 Technology and systems

Franke and Piller (2002) wrote that the following three things are needed for successful configuration: 1) the core configuration software that the customer uses to customise the garments; 2) a feedback tool that visualizes the choices the customer has made; and 3) the analysis tool that translates the choices into a production order. In addition to the configuration tool, a flexible manufacturing system is needed (Pine et al., 1993). The development of knitting machines has made it possible to answer very quickly to customer demand (Choi and Powell, 2005) and the development of visualisation tools has made it possible to instantly show customers what they ordered. Research question 3 aims to analyse the necessary technology for mass customisation systems.

2.6.1 Knitting technology as an enabler for mass customisation

The first examples of knitted fabrics date back to the 15th century AD in Roman Egypt. The first record of knitting in Europe is a painting from 1350 from Northern Italy (Spencer, 2001). Since then, knitting has developed to flat- and circular-bed knitting machines via the framework knitting machine. The first industrial-type knitting machine, “The Stocking Frame,” was invented by William Lee of Calverton in 1598 (Wikipedia, 2008). Industrial knitting has developed from Cut and Sew to Complete Garment, and Figure 2.9 illustrates how it has evolved. In Cut and Sew, knitted panels are cut into shape and sewn together to create a garment. It wastes material and is time consuming in cutting and sewing. Fully Fashion and Integral Knitting are rather similar, but the main difference between them is that Integral Knitting makes it possible to knit pockets on the garment. The benefits with Fully Fashion and Integral Knitting are that little material is wasted and there are no cutting processes after knitting. The complete garment technique is based in flat bed knitting, as are the three other knitting techniques (Figure 2.9).
Complete Garment knitting technology is a further development of the flat-bed knitting technique of knitting the entire garment in one piece, hence the name Complete Garment. Garments knitted with the Complete Garment technique have been on the market since 1995 (Hunter, 2004) and it has several benefits compared to older knitting techniques. Figure 2.9 explains the development of knitting technology from Cut and Sew to complete garment.

Depending on what type of knitting technique that is used, different customisation options will be available for the customer and the complexity of these design options will reflect on the supply chain. The different knitting techniques offer different flexibility but also different appearance of the garments and a tradeoff has to be made between customisation options and manufacturability.

2.6.2 System design

Multiple choice systems or configuration systems are the core communication tool, both for new and old customers. Systems like these are also known as
configurators, choice boards, design systems or tool-kits. The system is the interface between the customers and the companies so many aspects other than technical specifications have to be considered when designing it. The success of such a system is not defined only by its technological capabilities – how well it operates and matches the selling environment and how easy it is to use is equally important as the integration in the company’s profile. Multiple-choice systems do not have to be based on software although most of the existing systems are. In order for a multiple-choice system to work properly and provide the customers with enough feedback to decide on a purchase, the following three components are needed (Franke and Piller, 2002):

The core configuration software presents the choices to the customer and guides the customer through the process of designing the product.

A feedback tool presents the choices the customer has made in the configuration system. In most Web-based systems the feedback consists of a picture of the product and the price.

Analysing tools finally translates the customer’s choices to a bill of material, production order and production schedules. The analysing tool translates a customer’s specific order into lists of material, production orders and data sent to the knitting machine. The analyzing tool also sends data about material use and other logistics-related figures to the enterprise resource planning (ERP)- and (material resource planning (MRP) systems.

Buying mass customised products is not the normal way of shopping, at least not for most people. In an ordinary retailer the customer is allowed to see the finished garment before purchasing it. Creating an environment where the customers feel safe includes three main tasks besides the design. The user has to learn what is possible with the system, and he or she has to try the different possibilities and learn from the errors they make, therefore making it important for the system to be as simple and easily viewed and navigated as possible. A system also has to allow for comparing different results. Because of its central role, the multiple choice system is the most important entity in a value chain for mass customisation and it is important for the developers to consider all the aspects of a purchase, not only the technical issues (Piller et al., 2003).

2.7 Design

When a collection is started, it should be very clear who the design is for. According to Udale and Sorger (2006), there are two main factors a designer has to consider.

- What kind of expression does the fashion company desire from the garment? Is it haute couture, ready to wear, luxury superbrands, mid-level brands and designers, independent designer labels, casual and sportswear brands, high street (chain stores) or is it a supermarket?
- The type of garment is also a key issue for designers: casual wear, jeans wear, sportswear, swimwear, underwear, evening wear, tailoring, knitwear or accessories.

Additionally, for mass customised garments the designer has to address the manufacturability issue to make sure that it is possible to produce the
garment once the customer has ordered it and to be able to guarantee quality. Research question 4 aims to analyse how design for mass customised garments can be improved.

2.7.1 Design for mass customisation

The major challenge with designing for mass customisation is to ensure quality and lead-times and still offer an interesting selection for the customer. Therefore it is vital to select the right models and details from the very beginning because once the items and product family architecture are specified and produced, it is expensive and time consuming to make changes. Not only does it take time to re-program the knitting machine but new size samples have to be produced, the old ones have to be discarded and the ordering documentation has to be updated.

The product architecture for customized garments is more complex than the product architecture for regular knitted garments, since customers are going to design the garments themselves, which may end up in more combinations than if a designer would design it. Tseng and Jianxin (1996) wrote that there are three key enablers for successful design for mass customisation. They are optimizing reusability and commonality of the design, creating a uniform product family structure, and integrating the value chain.

2.7.2 Product design

Tseng and Jiao (1996) have suggested a framework for developing mass customised products, which they call product family architecture (PFA). The basis of a PFA is selected upon customers’ needs, repeatability in design and order fulfilment, the ease of configuration, and the appropriate aggregation level. The aggregation level is on which level the building blocks are assembled. For example, in knitwear the aggregation level is on different levels depending on what knitting technique is used. If the aggregation level is too low then there will be too many building blocks and the design process as well as configuration and fulfilment processes will be too complicated. If the aggregation level is too high then there might not be enough choices for the customer. Tseng and Jiao (1996) defined the following framework for formulating a PFA for mass customised products:

1. **Functional requirement of the garments** - The first step is to define the functional requirements of the garments.
2. **Identifying design parameters** - Design parameters should be chosen based on their ability to fulfil the functional requirements.
3. **Cluster the design parameters into building blocks** - When the design parameters are identified they should be clustered into groups and translated into modules.
4. **Granularity trade-off** - The trade-off between the options for customisation and what the supply chain and customers can handle. There is also a limit on how many choices a customer is able to process without confusion (Huffman and Kahn, 1998).
Mass customised products usually build on pre-engineered modules, which has many similarities with platform design. Muffatto and Roveda (2002) describe a platform design as a set of subsystems and interfaces intentionally planned and developed to form a common structure from which a stream of derivative products can be efficiently developed and produced. Companies use product platforms to reduce complexity (Huang et al., 2005), something that also mass customisers would strive for.
3 Methodology

This chapter introduces the reader to how the research in the thesis was conducted, what methods that have been used to collect data and how the data was transferred into information. It also elaborates on the abductive approach in relation to the time line of the thesis and the challenges with the chosen methods.

When a method is chosen it has to be remembered that it will include compromises. However, choosing the method carefully will be a prerequisite for good research. The methods we chose can be seen as guiding principles for the creation of knowledge and methods that have to fit both the researchers presumptions and the focus problem (Arbnor and Bjerke, 1996). This chapter presents the methods that have been used in the research in this thesis.

3.1 Finding the right method

Supply chain management is a complex research field, consisting of many different forms of research questions, which cannot all be solved with one methodology. Traditionally, within logistics and supply chain management quantitative research has been rewarded ahead of qualitative and researchers usually belong to the positivistic paradigm (Näslund, 2002). Quantitative researchers are often regarded to belong to the positivistic paradigm. A true positivist has to believe that an objective world exists, one that can be studied with objective methods. Quantitative methods include statistical testing of survey data, simulation and model building. Such methods are usually found in the natural sciences where the studied object can be isolated in a laboratory environment where a few variables can be analysed across a large number of observations. The results from such experiments can often be generalised whereas the results from qualitative investigations are harder to generalise.

There is nothing wrong with quantitative methods but using only one type of method on a diverse research area would result in biased research results and lack of understanding of the real problem (Arlbjorn Stentoft and Halldorsson, 2002, Kovács and Spens, 2005, Näslund, 2002). Taiici Ohno, one of the brains behind Toyota’s production system, described the problem with only relying on one type of data (Liker, 2004):

“Data is important but I place the greatest emphasis on facts.”

To operationalise this he had what is referred to as “Ohno’s circle,” which is an introductive exercise when starting employment as an engineer at Toyota. Supposedly one day is spent in a circle on the factory floor just watching and observing production processes going about the observer. Afterwards the new employee could marry the observations with the data and create knowledge.

3.2 Logical reasoning

There are basically three approaches to research: inductive, deductive and abductive reasoning. In deductive reasoning hypotheses are created from general laws and tested on specific cases. Deductive positivism seems to be the
dominant research approach in logistics, which is surprising since logistics is a rather new research area and such reasoning is mainly used to test existing theories. In *inductive reasoning* specific cases, or a collection of observations, are studied to create general laws and theories. The latter one of the approaches, *abductive reasoning*, comes from the insight that great advances in research does not originate from pure deductive or inductive reasoning but rather a combination of the two (figure 3.1). Abductive reasoning starts with an observation of a real-life event (1). This observation is then matched against existing theories (2) in an iterative process (Kovács and Spens, 2005). Dubois and Gadde (2002) calls this process *systemic combining*. The aim with systemic combining is to understand the new phenomenon and to create a new theory or new framework that explains the phenomenon (3) and finally to apply the conclusions (4) (Kovács and Spens, 2005).

**Figure 3.1 Abductive reasoning (Kovács and Spens, 2005).**

Action research has similarities with abductive reasoning and systemic combining, the iterative process of theory matching with real life observation is also found in the description of action research methods where concepts are developed and tested in an iterative process called action-reflection cycles (McNiff and Whitehead, 2002).

The Knit on Demand project has its starting point in the performance measures of fashion supply chains and the notion that they could perform better if the production and logistic operation were more flexible and customer oriented.

### 3.3 Qualitative research

Näslund argues that logistics research, since it covers a complex research field, needs qualitative research and especially action research to cover all aspects of it (Näslund, 2002). It does not mean that the methods have to be complex but they have to attack the research area from several flanks.

According to Bensabat et al. (1987), there are three different types of case studies as they appear in academic journals.

1. **Normal case studies** - with a clear objective in the research. Could be argued to be a traditional, positivistic research but has included real world information to the system.
2. **Applications descriptions** - a practitioner reports on success stories of the implementation of a certain application. May not be considered as case study research since the author’s objective was not to conduct research.
3. **Action research** - the process of change becomes the main subject of the research and the researcher is a participant in the change process. Action researchers want to conduct research while effecting change.

### 3.3.1 Action research

The core idea of action research is that the researcher does not limit him- or herself to observing an object but actively engages in the process of developing the object and the knowledge connected to the object. In action research the process of change and development is the main research focus and authors try to contribute both to the development of an organisation and to the development of science (Näslund, 2002). Action research challenges a predominantly positivistic research society were quantitative research methods are regarded higher than qualitative methods. Action research suits the field of supply chain management well as a complement to other research methods. Supply chain management is a complex research field; and thus, it should not only be attacked with one research method. Winter (1989) writes that good action research includes attacking the studied object from several directions. It is so that some problems require a multitude of research methods to find a solution. The problem with action research is that there is no established framework for evaluating the results from action research (Näslund, 2002). That connects to McNiff’s and Whitehead’s (McNiff and Whitehead, 2002) suggestion that action-research sometimes requires different presentation techniques than the linguistical ones.

**Methodology**

The methodology of action research is similar to the Plan Do Study Act (PDSA) cycle, often used for process improvement within different organisations but with the addition of critical reflection and connection to theoretical framework between the iterations. Instead of PDSA, it is described as Plan, Observe, Act and Reflect (POAR) (Figur 3.2).

![Iterative action research loop](image-url)
McNiff and Whitehead (2002) suggest the following six steps for the action researcher to take in the POAR-loop:

1. Review current processes
2. Identify what we need to improve
3. Imagine a way forward
4. Try it out
5. Take stock of what happened
6. Modify plan and continue with action

In order to keep as high academic level as possible the results of an action research project can be tested using more accepted research methods such as value stream mapping, statistical analysis of documents and interview, what if-analysis, interviews, etc.

Näslund et al. (2006) reflect that the goal of action research is not to find the cause and effect relations nor to generalise, but rather to understand and develop the processes in joint learning within the context studied. McNiff and Whitehead (2002) also focus more on the learning in the organisation than on describing cause and effect relations.

**Critisism**

Criticism has been that the studied objects have too much to tell in their stories and therefore the presentation is not comprehensible (Näslund et al., 2006). It is however suggested that action research methods require different presentation techniques than what is traditionally found. A report of an action research process would only be a linguistic explanation of the studied object, whereas a product or a film from the research process could explain the process better (McNiff and Whitehead, 2002). Another criticism is that action research resembles consulting more than rigorous research. However, researchers require more documentation than a consulting firm and the results are theoretically justified (Näslund et al., 2006). Action researchers also use a more cyclic approach that includes critical reflection on the results. Yet another critique is that the action researcher has too much influence on the results. However, the studied object, which is the Knit on Demand project, is influenced constantly by human actions since it is not kept in an isolated environment. The problem with biased results is solved by a multidisciplinary approach in the research team.

**Validation**

Validation has to do with what you say is believable and to legitimise the knowledge that has been created. Traditional research wants validation, generalisation and replicability of results, but action research is often conducted on single study objects where generalisability and replicability of the results are not applicable. According to McNiff and Whitehead (McNiff and Whitehead, 2002), action research can be validated by self validation, where the researcher tests the assumption against others in the research community. Colleagues validation where a critical friend or a validation group helps out to validate the results. A group of people from the duration of the research process is
gathered and invited to approve the results. Or by academic validation where the results are tested in the academic society, which can sometimes be problematic due to technical rationality within academia. The first two methods for validation would not be rigorous enough for most people in academia and the latter method for validation would be preferred. Winter (1989) suggests six principles for validating action research. These have some similarities with the criterias for judging the quality of research designs (Yin, 2009).

1. Offer a critique to the report in which the author reflects over what has been done (Winter, 1989). This criteria can be connected to the sixth criteria where the researcher connects the results to existing theories. Yin (2009) writes that for the sake of internal validity a researcher should address rival explanations.

2. Criticise the studied objects and their rate of changing characteristics (Winter, 1989). A case study researcher has to be prepared to accept shortcomings in the used measurements mainly because all conditions are not known in advance (Yin, 2009).

3. Be a collaborative resource for people who want to learn.

4. Accept risk as an inevitable part of creativity.

5. Attack the problem from several angles (Winter, 1989). Yin (Yin, 2009) writes that for the sake of construct validity one should use multiple sources of evidence.


### 3.3.2 Case studies

Case studies have commonalities with action research; both methods are considered to be qualitative by the positivists (Näslund, 2002), which is a target of similar critisism. Yin (2009) describes a case study as:

“...an empirical inquiry that: investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident.”

Case studies are often considered to be qualitative by the positivists, but Yin (2009) writes that by triangulating qualitative and quantitative data facts are created. The quality of action research and case studies is tested in similar ways. However, Yin (2009) is more specific in the criterias of testing the quality of a case study than McNiff and Whitehead (2002) and uses these four criteria to judge the quality of a case study:

- **Internal validity** – to what degree the findings correctly map the studied phenomenon.
- **External validity** – to what degree the findings can be generalized.
- **Reliability** – to what degree the findings can be replicated or reproduced.
- **Construct validity** – identifying correct operational measures for the concepts being studied.
**Triangulation of data**

In order to make the results from the risk analysis reliable, the *multiple source of evidence* and *data triangulation* approach has to be used. Jick (Jick, 1979) writes that triangulation of methodologies heightens qualitative data to its deserved prominence and at the same time makes use of quantitative data. There are four types of triangulation: data, investigator, theory and methodological triangulation. For this case study mainly data and investigator triangulation is used. When pursuing triangulation of data there are conditions that have to be fulfilled. For true triangulation, *upper portion triangulation*, data from different surveys are compared and conclusions are drawn from that. For *lower portion triangulation* the conclusions from different surveys are compared (Yin, 2009).

3.3.3 Simulations

A simulation opens up a window for analysing a process or a method where there is no full-scale environment available. It can be defined as an “*imitation of the operation of a real-world process or system over time*” (Banks et al., 2004). A simulation is an appropriate tool when new policies, production processes, information flows and decision rules need to be analysed without interrupting the ongoing processes of the real system.

When the system is modelled it is important to understand what is included in the system and what is not. A system is a group of objects that interacts with each other to accomplish a purpose. Outside the system is the system environment, which often affects the system and it is necessary to decide on the boundaries between the system and its environment.

**Validity and reliability**

To ensure the correctness of the simulation and its result, it has to be validated and verified. Banks et al. (2004) list a number of methods for validating the simulation, three of which were used in the simulation studies in this thesis: 1) have the model checked by someone other than the developer; 2) closely examine the model output for reasonableness under a variety of settings of the input parameters; and 3) present the simulation in a graphical interface that makes it easier to analyse the correctness of the simulation. Since it was not a very complicated simulation, the methods used to validate its reliability were considered sufficient.

3.4 Quantitative research

Numerical information is everywhere and we use quantitative data all the time and quantitative research uses numerical data to explain situations or object. Business problems often contain quantitative elements and using numerical data enhances our understanding of a situation or a problem. It is particularly important in business to be able to reinforce decisions based on reliable information. The benefit of numerical data is that it offers an objective and exact view of the situation. Numerical data also has the advantage that it can be
interpreted by others since there are often standard measurements and calculation methods (Waters, 1994).

The data collection is a key process in any research but collecting data is expensive and time consuming; so it is important to know what the data will be used for. There are several classifications of data. Data can be qualitative/quantitative, nominal/ordinal or cardinal, discrete/continuous and primary/secondary. Cardinal data is easy to analyse since it can be directly measured using common measurements such as cost, time and length; therefore, it is most relevant to quantitative research. Data collection often uses sampling where data from a sample of the population is used to explain the behaviour of the entire population (Waters, 1994).

Qualitative research methods use primarily numerical data, are rather straightforward and distinctive in its design and usually has a deductive approach (Bryman and Bell, 2011). Therefore, quantitative research methods add to this thesis that has a more general qualitative research approach.

### 3.5 Research process

The Knit on Demand project started in the spring of 2006. The development of the business concept started almost immediately in 2006 and kept on for three years to 2009 when it continued to be tested for a little more than one year. From 2006 to 2011 the project was analysed from different perspectives. Figure 3.3 explains when each of the phases of the project took place and how they are connected to each of the papers.

![Research chronology for concept development and collection of data.](image-url)
3.5.1 Action research: concept development

The process of building the Knit on Demand business concept, keeping the novelty of the original research proposal and making it work in its real context was more time consuming and difficult than originally anticipated. Figure 3.4 illustrates the action research process that developed the Knit on Demand project.

![Figure 3.4 Phases in the concept development.](image)

In abductive reasoning there is an iterative process that matches real life observations against theory (Kovács and Spens, 2005). This loop of matching theories and real life observations share similarities with the iterative process of action research (McNiff and Whitehead, 2002). In the process of developing the Knit on Demand concept these methods have been used. The project started with a notion that there are better ways to produce garments than the current practises. After that the Knit on Demand project was developed as a way forward to a solution that addresses the issues of the current practises. In figure 3.3 there are PAOR loops. In the act-phase of the project the ideas were tested with the involved companies, sort of a reality check for the researchers. If they were found useless, which they generally were towards the end, they went back into the loop and were reflected on. The two stages act and observe melt together. Very much of the research has focused on finding an accessible road forward and matching the researchers’ ideas towards reality rather than against theories until the stage of that reality, ideas and theories were close enough to be functional. Here follows a short description of the actions in each of the concept development processes in Figure 3.4.

**Complete garment system**

The complete garment system was beautiful from a supply chain perspective, no waste and instant delivery exactly according to customer data. However, from an investment perspective it was considered too risky to invest a tenth of Ivanhoe AB’s turnaround in a research project without any proven results.

**Smart retail system**

Smart retail system is a retail system that is built on radio frequency identification (RFID). The system is built for cross-sales and up-sales and not for mass customisation, which made it troublesome. Also, the system required risky investments in computerized systems and in the retail space. The
company that sold the system was based in Hong Kong where they also had two retailers using the system. The system was tested in Sweden in a mock-up store but there would be troubles fulfilling the purpose of the Knit on Demand project with the system.

**Fully Fashion**
Sales of customized knitted sweaters started in the fall of 2009. Since a Complete Garment knitting machine was too expensive and the smart retail system was neither smart enough nor good for mass customisation, the collection was now built on Fully Fashion garments. Fully Fashion offered the best combination of design options, manufacturability and quality.

*Validity and reliability of action research*
Since the concept was developed and tested, there is no doubt that the results from the action research performed has high internal validity. The results from action research may also be presented in other forms than purely linguistic (McNiff and Whitehead, 2002), in this case in the shape of a supply chain. The action research is performed on only one project with two companies and therefore the external validity can be discussed. It is not certain that the results from the research can be generalised since the environments at SOMconcept and at Ivanhoe AB are unique for them. However, insights from the development of the concept can be shared with others. In order to make the research as valid as possible the phenomena was also analysed with several different methods, both qualitative and quantitative.

### 3.5.2 Case studies
According to Ellram (1996), a case study, which is generally considered to be a qualitative research method can include quantitative data, is not the norm but there is nothing wrong with doing it. Yin (2009) does not exclude quantitative methods in case studies either, instead they should be used as support when triangulating several data sources to create a real understanding of the problem. Mangan et al. (2004) also want to see more combinations of qualitative and quantitative methods in order to enrich the discipline of logistics. Taiici Ohno did not reject quantitative production data either, instead he saw the use of combining qualitative observations and quantitative data to create facts.

**Case study consumers**
The purpose of case study number one was to explore what the customers think about the Knit on Demand concept. From the point of entering the store until they received the finished garment.

The first source of information is a qualitative questionnaire, the purpose of which was to analyze how the customer experiences the configuration process and what type of customers are buying the garments. It is based on the configuration process for mass customized products suggested by Franke and Piller (2002) (Figure 3.5). Each of the questions are related to one or several steps of the configuration process.
In addition to the questions about the configuration process, three questions (Goldsmith et al., 1999) are asked to define whether the customer is a fashion innovator, a fashion follower or a late adopter. The questions concern consumer shopping behavior, spending, and general interest in fashion. All thirty customers were contacted and asked if they wanted to participate in the interviews. Those who were willing to participate were contacted via telephone. Eight customers were interviewed and each interview lasted for approximately 30 minutes.

The second source of information is the order sheets from the customers. From the order sheets information regarding sizes and size adjustments have been analysed. There were in total 37 order sheets from September 2009 to December 2010 from 30 different customers. There is a risk that customers who do not fit into standard sizes were self-conscious about their size. Therefore, in order to secure the integrity of the customer data, information about size and size adjustments were separated from personal information such as name and telephone number.

The third source of information is the design process, which has been analyzed, both passively from an observing point of view and actively by participation. The store staff was also interviewed about the design process and how they assisted the customers in designing the garment.

Since this is a business concept and the development of each part is done together with the companies, there will also be results and conclusions from those sessions.

*Validity of results*

The results from the case study is from real life observations on actual customers who are spending their own money in a real store. Thus, based on the internal validity, the results are true for this particular concept. The results are not fully generalisable since they come from only one store and the customers shopping in that store. However, the results are more reliable than for example a simulation on a store or an experimental store. Since it is a case study on human beings it is impossible to replicate and get the exact same results.

*Case study value stream mapping*

Case study number two maps the supply chain processes from the customer inquiry to the the delivery on a final product. The case study was conducted during spring 2010, after sales had been going on for seven months. The supply chain processes were mapped using the "value stream mapping" method.
technique, which is a method developed in order to find and eliminate waste in production flow (Bergman and Klefsjö, 2007).

The study begins with the customer entering the store and purchasing a garment. It then follows the order back to the customer order decoupling point (CODP) where the order becomes a garment. The study continues through the final delivery to the customer. This paper does not consider purchasing and delivery of raw materials or strategic planning, since the supply of raw material to the customized knitwear is taken from the inventory that supplies ordinary production. The data presented in the paper comes from one year and three months of observation, which started in September 2009. Production of mass customised knitwear stopped in December 2010 due to capacity constraints in the sampling factory.

Validity and reliability of results
The results from the value stream mapping case study is from real life observations of a production process. Since other companies have similar knitting and sewing equipment the results from the production part of the value stream mapping can be generalised. The production process can be replicated if the exact same garment is ordered one more time so the results can be considered reliable. For construct validity reasons we have used standard measurements for the fashion business and for production technique.

Case study risk evaluation
The risk analysis consists of two parts. In the first part, performed in 2007, the conventional supply chain was analysed and it was also suggested how the Knit on Demand concept could reduce those risks. A number of deep interviews was performed with the production manager at the knitting company and the "What-if" analysis was chosen as a tool for identifying risks. A “What-if” analysis is a speculative tool often used when developing processes. When performing a “What-if” analysis a number of questions are formed such as: What if…happens? How a “What-if” analysis is deployed depends very much on the situation. It is important that the team answering the questions is skilled and multidisciplinary to cover all aspects of the analysed situation (Harms-Ringdahl, 2001).

In the first risk analysis in 2006 there was only one company exposed to business risks. In the spring of 2008 SOMconcept started to become seriously involved in the project and with them a sales channel for the garments opened. Instead of producing and selling the garments in Gällstad it was now decided that the garments should be sold in Stockholm at SOMconcept and produced by Ivanhoe in Gällstad. Thus, the risk analysis has expanded to figure 3.6.
Figure 3.6 Sources of risk in the Knit on Demand supply chain, developed version of Christopher’s and Peck’s model (2004) for sources of supply chain risk.

Validity and reliability of results
For validation and reliability purposes triangulation of data has been used, in this case study a mix between upper and lower portion triangulation. Figure 3.7 explains how the data converges triangulation in the “What-if” analysis, which is then verified.

Figure 3.7 Triangulation of data and sources of evidence.

For consistency the risk evaluation tool was the same as the risk analysis tool, i.e., a “What-if analysis” where all the risks were placed according to their magnitude in a probability-consequence diagram (scale: 1-10). Since the set-up of the supply chain was not the same as originally intended it was difficult to replicate the first risk analysis. Moreover, not every participant from the first risk analysis could participate in the risk evaluation. We did however use the exact technique and the exact same measurements for the risk evaluation. These techniques and measurements are commonly used in risk management why the construct validity is acceptable.

Case study pants
The study can be seen as an experimental study with real customers as test subjects. A more conservative view is to regard it as a case study, as the representativeness is difficult to assess. A consecutive sample strategy was used. All ordered customized pants between 2006 and 2010, i.e., from the time SOMconcept actually began to offer customised pants until the time the data collection was suspended in order to begin the analysis, was included in the sample. In total, 494 customised pants were ordered during that period. For each garment, the customer completed an order sheet in cooperation with the
staff in the store. The sheet included, among customer demographics and similar kind of data, information about the type, model, colour and size of the garment, but also information about individual adjustments to be made in length and waist as well as information about matching stitching thread colours. The study was based on the information in these 494 sheets.

Proper parametric methods, t-tests and ANOVA with post hoc testing with Dunnet’s T3, were used to compare means. Correlation between sizes and other variables were analysed with non-parametric methods since size is ordinal.

Validity and reliability of results
The case study is conducted on real customers in a real environment where the actual customers are studied. Since the actual customer behaviour is studied the results are more generalizable than if the study would have been performed using a survey or in a laboratory environment.

Simulation study 1
Paper I is built on a simulation study of the Design in Shop concept. The purpose of the simulation was to analyse the concepts’ performance regarding demand fulfilment time, production time and system efficiency. The model was built in AutoMod with the Logistics Department at the School of Engineering at the University College of Borås. AutoMod is a system for building models and simulating detailed design and production processes. Version 11.2 of AutoMod was used for this particular simulation.

The simulation method used is a process-interaction method that simulates the flow of objects through a system and the interactions of the objects with the system. The model is built as a discrete event model, which means that the state of the system changes discretely at a fixed set of points over time. Objects move through the system until they are delayed, enter an activity or have been completed by the system. The emphasis in the model has been on time: production time, fulfilment time and system efficiency. Since time probably is the most important performance indicator in production and logistics and the aim of the project is to reduce lead-time, the simulation method suits the means.

Input data used in the simulation model was based on information from knitting machine manufacturers and data from the Prototype Lab at the Swedish School of Textiles. Customer behaviour data were gathered at the location of the future store. Based on the data on how often customers are entering the store, an exponential distribution was used to model random arrivals at the store. The exponential distribution is without memory, which means that customers arrive at the store independent of each other. Each run of the simulation corresponds to one month of customers entering the store. The output data were summarized in charts and visualized for better understanding of the system’s performance.
Validity and reliability of simulation 1

To ensure the internal validity of the simulation, the following three methods were used: 1) have the model checked by someone other than the developer; 2) closely examine the model output for reasonableness under a variety of settings of the input parameters; and 3) present the simulation in a graphical interface that makes it easier to analyse the correctness of the simulation.

Simulation study 2

Simulation study 2 is a part of a study of Shima Seiki’s order made systems. We examine the two systems through simulations that compare lead-time, efficiency and the impact they had on retail sales of complete knitted garments. The field work was carried out at the firm of Shima Seiki, supplier of knitting production equipment and inventor of the prototype co-design system Ordermade WholeGarment®, and the fashion companies Factory Boutique Shima (Wajima Kohsan Ltd.) and SOM Concept. A research project entitled “Knit on Demand” at the Swedish School of Textiles, in collaboration with the SOMconcept, was also a source of information. The discussions, interviews and a study of the co-design process in Japan represent the primary data collection. A literature survey comprised the secondary data. At the Japanese shop, one person acted as a customer and a garment was customised through the co-design process from beginning to end. Thus, information for the development of the simulation model was collected on-site in the real shop environment at Factory Boutique Shima. The customisation processes was studied in two formats: a) Manual WholeGarment co-design; and b) Ordermade WholeGarment®. Both were evaluated and assembled as models for simulation in AutoModTM in order to compare their performance. Qualitative interviews with factory representatives at Shima Seiki and retail staff at Factory Boutique Shima developed information about the two procedures.

Validity and reliability of simulation 2

Verification of the input provided and the results of the simulations are compared with that provided by the three sources. For internal validity of the simulation there are some limitations of this study due to absence of actual customer behaviour in the data and the fact that it is based on a simulation, rather than observation in a real shop environment. The measurements used in the simulation are the same as those used in the textile manufacturing business.
3.6 Summary of methods

The methods used in this thesis have been chosen on their ability to fulfil the purpose of the Knit on Demand project and the analysis of the project. Table 3.1 presents a summary of the used methods in each paper.

Table 3.1 Summary of methods.

<table>
<thead>
<tr>
<th>Paper #</th>
<th>Scope</th>
<th>Purpose type</th>
<th>Main method</th>
<th>Empirical sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Design for mass customisation</td>
<td>Describes the development of Knit on Demand</td>
<td>Action research</td>
<td>Knit on Demand project</td>
</tr>
<tr>
<td>II</td>
<td>Order fulfilment process</td>
<td>Describes a simulation</td>
<td>Simulation</td>
<td>Knit on Demand project</td>
</tr>
<tr>
<td>III</td>
<td>Risk</td>
<td>Evaluation of supply chain risks</td>
<td>Case study: &quot;What if?-analysis&quot;</td>
<td>Two What if?-analyses on the Knit on Demand project</td>
</tr>
<tr>
<td>IV</td>
<td>The customisation process</td>
<td>Describes a simulation</td>
<td>Simulation</td>
<td>Knit on Demand project and Shima Seiki factory boutique</td>
</tr>
<tr>
<td>V</td>
<td>Customers</td>
<td>Describes why and how customers are purchasing customised garments</td>
<td>Interviews</td>
<td>Knit on Demand project, 37 customer orders, eight interviews</td>
</tr>
<tr>
<td>VI</td>
<td>Supply chain management</td>
<td>Describes the Knit on Demand supply chain</td>
<td>Case study: Value stream mapping, interviews, observation</td>
<td>Knit on Demand project</td>
</tr>
<tr>
<td>VII</td>
<td>Customisation of pants</td>
<td>Explores how customers customise pants</td>
<td>Quantitative case study</td>
<td>SOMconcept's pants, 496 customers</td>
</tr>
</tbody>
</table>
4 Summary of appended papers

This chapter presents a summary of the included papers and of the individual studies. In the end of the chapter the interconnections between the papers are presented.

The papers that are included in the dissertation are all describing or analysing the Knit on Demand project from one point or another except Paper IV and VII. Paper IV analyses a Japanese store’s concept of the same kind of Knit on Demand concept. In that, simulation data from the Knit on Demand project have been used to fill information gaps. Paper VII analyses how customers choose to customise and purchase pants in SOMconcept’s store, the same store where the Knit on Demand jumpers and cardigans were sold. The other papers attack the Knit on Demand project from different perspectives. Figure 4.1 highlights where in the model of the fashion business each of the papers fit.

Figure 4.1 How each of the papers fit into the fashion business model.
4.1 Contribution to papers

Table 4.1 highlights what each author contributed within each paper.

Table 4.1 Authors and their responsibilities in each of the papers.

<table>
<thead>
<tr>
<th>Paper #</th>
<th>First author</th>
<th>Second and n-th author</th>
<th>Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Jonas Larsson,</td>
<td>Pia Mouwitz</td>
<td>Pia and I developed and designed the garments together. The writing of the paper was done together so the authors have equal parts in this paper</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Joel Peterson</td>
<td>Jonas Larsson, Jan Carlsson, Peter Andersson</td>
<td>Joel wrote the paper, I collected input data, Jan assisted with feedback on the results and Peter made the simulation</td>
</tr>
<tr>
<td>III</td>
<td>Jonas Larsson</td>
<td>Joel Peterson</td>
<td>Joel assisted in the collection of data and in the first part of the risk analysis. I performed the second &quot;What if? -analysis&quot; and wrote the paper.</td>
</tr>
<tr>
<td>IV</td>
<td>Joel Peterson</td>
<td>Jonas Larsson, M Mujanovic, Heikki Mattila</td>
<td>Joel wrote the paper, I collected input data, Heikki assisted with feedback on the results and Mujanovic made the simulation</td>
</tr>
<tr>
<td>V</td>
<td>Jonas Larsson</td>
<td>-</td>
<td>Sole author</td>
</tr>
<tr>
<td>VI</td>
<td>Jonas Larsson</td>
<td>Joel Peterson</td>
<td>Joel assisted in collecting the data for the paper. I wrote most of the paper and Joel assisted with feedback.</td>
</tr>
<tr>
<td>VII</td>
<td>Jonas Larsson, Björn Lantz</td>
<td>-</td>
<td>I collected the data for the statistical analysis and Björn performed the analysis. Björn and have equal parts in writing the paper.</td>
</tr>
</tbody>
</table>

4.2 Paper I - Design for mass customised knitwear

The purpose of the article is, with a starting point in the research project Knit on Demand, to analyse and describe the development of a system for customising knitwear with a focus on the development of the garment. It describes the thinking and frameworks used to develop the collection of mass customised garments.
The garments are developed using the product family architecture framework. It consists of the following four main steps (Tseng and Jiao, 1996):

1. Define the functional requirements of the garment. What does the customer expect from it?
2. Identify design parameters. These should be chosen based on their ability to fulfil the functional requirements.
3. When the design parameters are identified they should be clustered into groups and translated into modules.
4. The trade-off between the options for customisation and what the supply chain and customers can handle. There is also a limit on how many choices a customer is able to process without confusion (Huffman and Kahn, 1998).

**Main findings**

The result of the development process is a collection of garments and the corresponding customisation options. Figure 4.2 illustrates the modules that make up the garment. These modules are based on the design parameters. There are in total circa 100 million combinations that all stem from one base module.

![Figure 4.2 Design parameters clustered into modules](image)

Figure 4.2 illustrates two finished garments. The left one is a V-neck in size medium with contrast fabric on the collar (not visible) and the right one is a deep V-neck in size small with contrast fabric on the collar (not visible).
The price of a customised garment is about 25 percent higher than for an equivalent standard garment. The increased price is mostly due to the knitting process that requires more control for a customised garment than for a standard garment.

4.3 Paper II - Knit on Demand - development and simulation of a production and shop model for customised knitted garments

The purpose of the simulation is to open a small window toward the future through which the demand-driven supply chain can be analysed. The paper presents a simulation of a shop model for customized knitwear, that in combination with complete garment technology and the concept of mass customisation creates a demand driven supply chain for customized knitted garments. The customer behaviour data from the model is based in a study at the fashion store where the garments are going to be sold. On average, one customer entered the store every six minutes during the nine opening hours per day. The data regarding equipment performance is gathered from the equipment suppliers. This paper presents the original idea of the Knit on Demand concept.

The model is built on the idea that a customer enters the store and then decides upon a purchase. If the customer decides on a purchase, he or she chooses either to purchase a garment from Designers Place or to design his or her own garment in the Design in Shop part of the store. If the customer chooses to buy a garment from Designers Place, an order is sent to the knitting machine and it knits another one to replenish the one that is sold. If the customer chooses to design an individualized garment, he or she uses a
multiple choice system to configure the garment. When the customer is satisfied a message is sent to the knitting machines to produce the garment.

**Findings**

The simulation of the model shows that it is possible to produce and deliver a garment within three hours. Table 4.2 presents the result of the simulation. Most of the garments’ fulfilment time varies between 120 to 300 minutes. Demand fulfilment time for cotton garments is an average of 206 minutes and 191 for woollen garments. The higher fulfilment time for cotton is due to the longer finishing process. The most interesting finding is that it is possible to deliver a personally designed garment in approximately three hours.

**Table 4.2 Demand fulfilment time in minutes for different materials.**

<table>
<thead>
<tr>
<th>Material</th>
<th>Minimum fulfilment time</th>
<th>Average fulfilment time</th>
<th>Maximum fulfilment time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>137</td>
<td>206</td>
<td>300</td>
</tr>
<tr>
<td>Wool</td>
<td>120</td>
<td>191</td>
<td>301</td>
</tr>
</tbody>
</table>

4.4  **Paper III - Evaluation of risks in a supply chain for customised knitwear**

The evaluation of risks in the Knit on Demand concept consists of two parts. The first part was performed in 2007 and the investigation revealed the most evident risks in the supply chain under study as well as in the proposed future supply chain. The second part was performed in 2011 and is an evaluation of the first risk analysis using the knowledge and the experiences from the project to verify or falsify the earlier results.

**Findings**

On average, the risk in a supply chain for mass customised fashion is reduced compared to a conventional supply chain. In the evaluation of the project, it turned out that some of the risks that were evident in the existing supply chain in 2007 or anticipated to have a high impact in the Knit on Demand project had no impact at all or were considered not applicable. None of the risks had high enough consequences to put the company in bankruptcy so risk level 100 is equivalent to loss of sales, exactly how much is difficult to measure since a potential customer who does not purchase seldom reveal themselves to the store staff.

In Figure 4.4 the average risks in the different stages of the project are presented. The stages are initial risk before the Knit on Demand project started in 2007, the expected result in 2007 of the project and the actual outcome of the project in 2011.
Figure 4.4 Average risks in the Knit on Demand supply chain.

The initial risk level was 427; the expected outcome of the project was a risk level of 24.7. However, the consequences of an event were expected to be more severe than in the initial state. The actual outcome of the project is a risk level of 21.3 with both reduced probability of an event and reduced consequences in the case of an event. The expected probability of an event was equal to the actual probability of an event, but the consequences were considered lower in the evaluation of the concept.

4.5 Paper IV - Mass customisation of flat knitted fashion products: simulation of the co-design process

The purpose of Paper IV is to analyse and compare two customisation concepts. One manual system and one digital configuration system. Both systems are developed by the Japanese knitting machine manufacturer Shima Seiki. The analysis is made on their business concept Factory Boutique Shima, which combines knitting technology and mass customisation on the retail level and it has similarities with the Knit on Demand project. As in the Knit on Demand project the customers are designing, or configuring, the garments themselves with assistance from the store staff. The boutique keeps fashion magazines, swatches of fabric, colour charts and sample garments for inspiration and ideas. A selection of garments in various sizes may also be tried on to assure a perfect fit. In the manual process of creating the customised item, the client’s measurements are taken by a shop assistant skilled in clothing design. The customer is allowed to choose between different materials, styles, colours and details. In contrast to the manual procedure just described, one of the Factory Boutique Shima stores has introduced a newly developed co-design system to make the interaction between the customer and the company more efficient. The Ordermade WholeGarment® co-design system functions as an interface between the customer and the manufacturer. Options are presented in several steps, allowing a customer to choose materials, styles, colours and such details as pockets and trims.
Results of the simulation

For Manual WholeGarment, the result varies from 146 to 409 garments per 200 hours of operation, depending on whether one, two or three shop assistants are available to assist with the co-design. Similarly, for Ordermade WholeGarment® co-design the result varies between 259 and 794 customised products, depending on the availability of one, two or three computers available for customer use.

The result shows that co-design with a configurator is more efficient in terms of numbers of customised garments than the manual co-design option. At the end of 200 hours of simulation, the result was 800 customised products via a configurator and 700 with manual help from a shop assistant. To show the capacity attainable through a configurator and illustrate the difference between the alternative co-design concepts, we have projected the outcomes assuming five personnel in the shop, compared with 1000 configurators. Our intention is to show what happens if the configurator can be accessed through the Internet at a retailing company’s Web page. The Ordermade WholeGarment® system (in this case the Internet alternative) enables over 8000 products to be customised, compared with less than 1000 for Manual co-design. This rests, of course, on the great difference between the number of in-shop personnel and the almost unlimited access to configurators on the Internet (five versus 1000), and illustrates the vast possibilities the Internet option provides to retailers.

The results of the Automode simulations show that a configurator will enable more clients to customise a garment compared with the Manuel Whole Garment alternative. However, the simulations do not show a significantly better result for the configurator alternative, but co-design via computer by each customer allows for fewer store personnel and thus lower costs for the company.

There is a significant difference between the two alternatives in how many customers they are able to serve during one time period. The Ordermade WholeGarment® system (in this case the Internet alternative) enables over 8000 products to be customised, compared with less than 1000 for Manual co-design. This rests, of course, on the great difference between the number of in-shop personnel and the almost unlimited access to configurators on the Internet (five versus 1000), and illustrates the vast possibilities the Internet option provides to retailers.
4.6 Paper V - Customer perspective on mass customised knitwear

The purpose of Paper V is to analyze the concept from a customer perspective, from the discovery of SOMconcept AB and Knit on Demand until the eventual purchase. There is little literature about why people buy customized products and how they experience the design and purchase process. It is suggested by the owners of a few businesses providing customized garments that customers buy them for basically three reasons: they cannot find the fit they want; they cannot find the design they want; or they cannot find the function they want. Not finding the right fit, design or function may include several aspects. The size may be wrong because the waist is too small or the arms are too long, but it may also be a style problem of if that particular silhouette is out of fashion.

Findings
It is often serendipitous that customers find the store and the Knit on Demand concept. Most customers more or less stumbled upon the store when they were out shopping, and some had read about it in a magazine. The customers are mostly ordinary customers but with some extraordinary needs, like long arms compared to the torso or a narrow torso compared to the length of the garment. They do, at first glance, seem more fashion conscious than the average person, since they have chosen to design a personalized garment and pay a rather high price for it. However, when asked about their consumption habits, it appears that they are about as interested in fashion as their social context and on an average they were not fashion innovators but rather fashion followers. Most important for these customers were the following: number one, fit; number two, aesthetics; and number three, the quality of the garment. Price is not an issue for the average customer as long as they like the garment and they know the garment will last in shape and color.

The customers found it relatively easy to customise their garment, due in great part to the friendliness and helpfulness of the store staff. Even if some felt a bit of initial confusion, all the customers felt comfortable when designing, again thanks to the store staff. Visualization of the end product helped much because of the sample garments, but some customers would have preferred a digital visualization of the garment to help them remember their choices. About half of the customers wanted more design options but they did not specify what they would like to change and why. The preferred lead-time is between one and two weeks, but some customers had to wait several months for their garment. Surprisingly, none of the customers could specifically tell the lead-time or the price of the garment. They did, however, talk about the quality and the fit of the garment and the excellent service they were provided with in the store. It has been thought that Georgio Armani once said: "Price is forgotten within a week; quality is never forgotten," and in the context of this paper, he probably had a point. Customers also
intended to use the Knit on Demand garments longer than their other garments since they like them better and felt that the quality was better than other garments that they owned. All the customers also thought it was a great experience to design their own garments and will definitely do it again, either with jeans, suits or with knitwear. The customers used words like "awesome," "cool" and "great experience" when asked to describe their experience. Even if the customers understood that there was a chance that some other customer would order a similar garment, they still enjoyed the sense of uniqueness that the design process gave them. Even if they did relatively few changes to the sample garments, they still felt like they had designed their own garment.

One of the reasons that the customers gave as to why they were buying customized garments is that they do not fit into the standard sizes. In table 4.3 the result from the analysis of the customer size data is presented. The size data comes from the size of the garments they have bought and the adjustments that have been done to the garments.

Table 4.3 Average adjustments of garment measurements.

<table>
<thead>
<tr>
<th>Type of change</th>
<th>Average (cm)</th>
<th>Standard deviation (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only sleeve</td>
<td>1.8</td>
<td>2</td>
</tr>
<tr>
<td>Only body</td>
<td>-0.3</td>
<td>4.63</td>
</tr>
<tr>
<td>Both sleeve and body</td>
<td>3.84</td>
<td>2.51</td>
</tr>
<tr>
<td></td>
<td>3.84</td>
<td>2.76</td>
</tr>
</tbody>
</table>

The average size adjustment was +1.13 cm on the body length with a standard deviation of 3.48 and +1.64 cm on the sleeve length with a standard deviation of 2.47. Some customers changed only the body length, only the sleeve length or both body and sleeve length (Table 4.6), and when dividing the customers into groups the result was somewhat different. Forty-one percent of the customers who only made one change adjusted within the size ranges that can be found in any store. Most of these customers would be fine with a standard, non-customized garment. However, the standard deviation is quite large, which suggests that there are customers who have made relatively large adjustments. Thirty-eight percent of the customers who changed both sleeve and body length had measurements that were on an average outside any existing standard, which means that they cannot find garments that fit them in traditional stores. Twenty-one percent of the customers did not make any adjustments at all.

4.7 Paper VI - The Knit on Demand supply chain

The purpose of Paper VI is to present the concept Knit on Demand from a supply chain perspective. The paper includes findings about customisation processes, technology and systems and logistic processes.
Findings

Figure 4.5 illustrates the Knit on Demand supply chain and the flows of material, finished products and information. Since it is an “on-demand” supply chain, nothing is supposed to happen in the supply chain until there is an order. However, a lot of things have already happened before the first order. Yarns, accessories and threads have been bought and are kept in inventory at the producer. Also, the design system and order sheets have been developed and are waiting for the first order. Since it is a rather short supply chain it has the capabilities to answer quickly on customer demand; the shortest theoretical response time is two days. In reality the shortest lead-time is about one week. Customers are promised to receive their garments within three weeks.

![Diagram of Knit on Demand supply chain](image)

*Figure 4.5 The Knit on Demand supply chain.*

Delivery time to stores in Stockholm or directly to the customer is one to two days. Before the customer picks up the garment at the retailer the labels are added and the customer is notified via phone or e-mail.

The target is to reduce the throughput time in the factory to fewer than five days, decreasing the total lead-time to one week. However, to reach that goal, the volume must increase to at least one garment per day. Then one knitting machine can be dedicated to the customised garments for one day. This procedure offers several benefits. The machine operator gets a sense of focus and learns the personality of the particular knitting machine being used. Additionally, if a customer decides that the finished garment is not what was ordered, he or she, according to Swedish consumer laws, is not allowed to return the garment unless the customer can prove that the company has not produced according to the order specifications, such as the wrong colour of yarn. In such cases the customer receives a new garment that meets his or her preferences.

One concern in the project was that customers would not be willing to pay the price for a customised garment, which retails between 1300 and 1600 SEK depending on the model and add-ons. However, few of the interviewed customers were concerned about price. They accepted a higher price as long as they got their unique garment or a garment that fit well. The production cost is 265 SEK for a standard V-neck garment; the wholesale price is 600 SEK; and the garment retails for 1400 SEK. Thus, the markup at the wholesaler is what can be expected for a fashion garment, around 2.5 times the wholesale price. The cost of delivery from the producer to the store is 50 SEK per garment with the Swedish post.
Figure 4.6 illustrates the production process in the Knit on Demand project. The total value adding time in the production process is 126 minutes. With set up times and waiting times the production lead-time is 136.5 minutes. However, when the cost of the garment is calculated, the total time is calculated using the standard allowed minute. For example, in the knitting production step the allowance is 100 percent due to downtime, set up time and problems that might occur with each new garment. Using SAM, the total lead time equals 179.7 minutes.

<table>
<thead>
<tr>
<th>Fully fashion + Cut and sew</th>
<th>Washing (rinse program)</th>
<th>Tumble drying</th>
<th>Steam &amp; Press</th>
<th>Cutting</th>
<th>Sewing</th>
<th>Finishing &amp; inspection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knitting</td>
<td>L/T = 33 min</td>
<td>L/T = 5 min</td>
<td>L/T = 60 min</td>
<td>L/T = 5 min</td>
<td>L/T = 15 min</td>
<td>L/T = 3,5 min</td>
</tr>
<tr>
<td></td>
<td>S/T = 5 min</td>
<td>S/T = 3 min</td>
<td>SAM = 69 min</td>
<td>SAM = 6,25 min</td>
<td>S/T = 2,5 min</td>
<td>S/T = 3,5 min</td>
</tr>
<tr>
<td></td>
<td>SAM = 5,75 min</td>
<td>SAM = 2,875 min</td>
<td>SAM = 22,5 min</td>
<td>SAM = 3,85 min</td>
<td>SAM = 69,45 min</td>
<td>SAM = 5,75 min</td>
</tr>
</tbody>
</table>

Customer orders trigger the production system; it begins with the customer design process, which starts when the customer enters the store and decides to buy a customised knitted garment. The customer is then guided through the steps of the design process by a tailor and is allowed to change the garment based on four parameters, namely: model, fit, colour and details. Within these four parameters there are additional steps, so the customer goes through nine design steps in total. It is a manual system that means that there is no visual feedback for the customer except for the garments in the store and the swatches of fabric. The tailor has to make sure that the customer understands what the end result will look like. If the image the customer has created of the garment does not closely resemble the end product, the customer might not be satisfied. When the customer is satisfied with the design, it is specified in an Excel document and sent to the manufacturer by e-mail and the order is confirmed by the producer.

One interesting finding from the project was that there were very few returned items. The ones that were returned, were returned because of mistakes made in production such as wrong colour or wrong size. Other mass customisers also have low return rates, usually less than one percent.

Paper VII - A quantitative explorative study on mass customised pants

Paper VII presents the results of an explorative study on how customers purchase mass customised pants. The purpose is to explore differences in customization between different types of pants and associations between different types of customization. The study is performed at SOMconcept AB in Stockholm who also sold the Knit on Demand jumpers. Customers can choose to customize their pants in the store with assistance from the store staff or they can do the customisation by themselves online, using SOMconcepts online configurator (figure 4.7).
Figure 4.7 SOMconcepts online configurator.

Fit
Customers can choose between three different models of jeans – slim, classic and wide fit; two different models of chinos – slim and wide; and two different models of slacks – slim and wide. Measurements are taken with measuring tape directly on the customer and translated to the nearest standard size by the store staff. For jeans that are size 28 to 38 and for chinos and slacks 44, 46, 48, 50, 52, 54 and 56, two measurement variables are used – waist and length. Customers can also make alterations on the model, if they for example would like a boot cut model or baggier pants.

Colours
Customers can choose between several different fabric qualities, with or without stretch, contrast fabrics as well as different colours of thread and stitching. There are also contrasting fabrics for inner lining and pockets.

Attachments
Customers can choose between different pockets and a different number of pockets on chinos and slacks models, button or zip fly on both chinos and jeans, and bronze or silver button and studs.

Findings
Customers with larger sizes tend to do more size adjustments on their pants, both on chinos and jeans, than customers with smaller sizes. The size adjustments are mostly towards longer and thinner silhouettes, which may suggest that thin, narrow and tall sizes are difficult to find in the regular outlets.
Jeans customers decrease the waist measurement more than customers who purchase chinos and especially slim fit that are on average decreased more in waistline than classic fit. Of the jeans customers, those who purchase slim fit jeans decrease the waistline more than those who purchase classic fit, who on the other hand lengthen the jeans more. Chinos customers with larger sizes tend to decrease the waist measurement more than customers with smaller sizes and they also lengthen their pants more than customers with smaller sizes. Chinos customers purchase almost exclusively slim fit models. Jeans customers with larger sizes tend to lengthen the garments more than customers with smaller sizes. Also, jeans with a classic fit are on average lengthened more than slim fit jeans. This suggests that taller men prefer classic jeans models. It may be the case here as well, tall men prefer pants that do not emphasize their long legs and therefore prefer a more classic fit ahead of the slim fit models. However, in contrast chinos customers purchase almost exclusively slim fit and there were no differences in length adjustment between chinos, jeans and slacks.

Customers do more adjustments of colours on stitching on jeans than on chinos and customers who purchase blue jeans tend to use more colours on the stitching than customers of black jeans.
### 4.8 Interconnections between papers

For a comprehensive view of the results in this thesis, the results are compiled in Table 4.4 and the interconnections are analysed.

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Design</td>
<td>Different choice of material gives different lead times.</td>
<td>Right design decreases risk.</td>
<td>Design impacts customer satisfaction.</td>
<td>Design impacts supply chain performance.</td>
<td>Size adjustments are equally important as design adjustments.</td>
</tr>
<tr>
<td>Paper II Simulation I</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Production lead-time on average three hours for cotton garments. Wool garments could reduce lead-times.</td>
<td>-</td>
</tr>
<tr>
<td>Digitalized configurator may decrease risk of misunderstanding the concept.</td>
<td>Risk of customers misunderstanding the concept is high.</td>
<td>Online configurator makes concept available to more customers and perhaps more comprehensible.</td>
<td>Manual configuration system is less efficient than an online system.</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Paper IV Simulation II</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Customer did not bother about supply chain performance measures such as price and lead-time.</td>
<td>Customers have a tall and narrow silhouette compared to average sizes.</td>
</tr>
<tr>
<td>Paper V Customers</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Paper VI SCM</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Paper VII Pants</td>
<td>-</td>
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</tbody>
</table>
5 Analysis

This chapter compares the results of the papers in relation to each other and to the theoretical framework in order to find answers to the research questions and finally the overall research question this thesis is aiming to answer, which is:

*How does a responsive supply chain for mass customised garments work?*

This is a rather ambitious question and the aim of the thesis is to contribute to the further development of fashion business and learn how companies can be more responsive to what the customer demands. The overall research question was broken down to four research questions, each of them guided by the overall research question, but covering one part of the concept. The first part concerns the customers and what they find important when they are buying a customised garment. It is chosen as the first part since the customers are the ones putting money into the system, and without the customers there would be no dissertation. The second part concerns the supply chain processes, i.e., the order fulfilment process and the associated risks. In order to make a concept where customers are allowed to design their own garments a production system is needed. It consists of different systems and technology. Part three analyses what is needed in terms of technology and systems for successful customisation. One important aspect of mass customisation is waste reduction. Part four analyses how the design of the garments can be improved to cater to more customers but also to make the system more efficient. Table 5.1 illustrates the research questions in relation to the papers and to the general model of the fashion business.
Table 5.1 Papers in connection to research questions

<table>
<thead>
<tr>
<th>Paper #</th>
<th>Research questions</th>
<th>Scope</th>
<th>RQ 1</th>
<th>RQ 2</th>
<th>RQ 3</th>
<th>RQ 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>RQ 1</td>
<td>Customers</td>
<td>Supply chain processes and risk</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>RQ 2</td>
<td>Order fulfilment process</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>RQ 3</td>
<td>Risk</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>RQ 4</td>
<td>The customisation process</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>RQ 5</td>
<td>Customers</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>VI</td>
<td>RQ 6</td>
<td>Supply chain processes</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>VII</td>
<td>RQ 7</td>
<td>Customisation of pants</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

5.1 Customers

Every supply chain starts with the customer since he or she is putting money into the system. Customers have explicit and implicit demands on a product and by analysing the demands the concept can improve.

Research question I: 
What components are necessary for the customers to purchase customised garments?

Niche customers

Almost eight out of ten customers of Knit on Demand garments made adjustments to the size of the knitted garment; they either lengthened, shortened, narrowed or widened it. This suggests that most of the customers that order Knit on Demand garments do not find the sizes they prefer in the regular outlets. Of these, about half changed both the body length and sleeve length; the other half only changed sleeve length. Customisation of sizes on knitwear is mostly toward longer and thinner silhouettes. Of the pants customers, a significant amount also adjusted the sizes towards longer and thinner silhouettes. The results of the pant study (Paper VII) and the knitwear study (Paper V) show that the average customer of customized jeans, pants and knitwear has a taller and more narrow silhouette than the average customer. The average customer of knitwear would have difficulties finding a garment that fit in a regular fashion outlet. Some are short and hefty as well, but the average customer usually lengthens a garment and decreases the waist.
measurement. There are standard sizes for many of the customers that would fit but there were some customers that were so tall and thin that not even the narrowest and longest size, at least in the Swedish system, would fit them. This means that there is a demand for this type of products and one of success factors for mass customisation is fulfilled (Da Silveira et al., 2001). However, there are not enough of these tall and slim customers to make it profitable for the fashion companies to produce their specific sizes of garments. One way of reaching out to these niche customers is to make the concept available online. Not only can one reach more customers, but more customers can be served per time unit (Paper IV). By the democratisation of the production tools, customers are allowed to be a part of the production process (Anderson, 2006). Da Silveira et al (2001) wrote that marketing conditions have be ready and with the Internet a market where niche products fit have opened up.

Service

For a mass customisation concept to function properly the customer needs a configuration tool. This is a system that allows the customer to design the garment in a way that does not confuse them. The system does not have to have a digital feedback tool, which according to Franke and Piller is necessary (2002). It will function well without one as long as the store staff are knowledgeable and are able to teach the customer about the choices she makes. Both the customers and the store staff has indicated that a digital feedback tool helps to explain the choices the customer makes, but not that the end result would be better with one. This relates to what Kurinawan et al. (2006) and Huffman and Kahn (1998) wrote about how customers like to customize garments. Customers prefer to have the choices presented in an attribute-based manner, that is the customer gives her preferences of a product and the store staff presents a number of options based on those preferences. The other method is called alternative-based presentation, that is the customers choose from all options without having the options narrowed down by the store staff. Customisation on-line is usually alternative-based since there is no physical person who can assist in presenting only the interesting options for the customer. The attribute-based presentation would be easier in a physical outlet since the store staff is available to assist. In this case the attribute-based presentation was used and the customers had mostly positive things to say about the presentation of the concept.

In the service element, the whole experience of customizing a garment is included. When asked to explain how the customers experienced the Knit on Demand concept they used words like “awesome” and “cool,” and they mentioned how they really liked the store staff since they were friendly and helpful (Paper V). So there is, in the Knit on Demand concept, more to the element of customisation than just receiving a garment that fits their preferences. The experience around the purchase is equally important. Gilmore and Pine (2007) describes a shopping experience in terms of authenticity – the more authentic a shopping experience is, the more the customers like it. Basically, it means that if you go and have your garments customised you want
it to feel like you are at the tailor. Since the store staff is assisting the customer while customising the garment and the estimated average time for a purchase is 20 minutes, it is bound that the store staff and the customer will get to know each other better than in a regular outlet or an online store, thus, creating a deeper involvement in the production process. From the four realms of a shopping experience, customising your garment would end up in the *escapist* realm since the customer is actively involved in the customization of the garment and is not passively watching it being designed.

About half of the interviewed customers in Paper V wanted more design possibilities. Even if the total number of combinations on knitwear was close to 100 million, they still wanted more. None of the customers indicated that they were confused by the configuration systems, something that might occur if the choices are presented in a not understandable way (Huffman and Kahn, 1998). The attribute-based configuration system may have helped to ensure that did not happen. Since the customer did not experience very much confusion, the system could still allow more options and, thus, satisfying more customers.

Customers were not bothered about lead-times or price; in fact, very few of the customers even gave price a thought. When asked about delivery lead-time none of the customers had thought about that either. This is also reflected in literature on mass customisation, where there is a lack of findings on how customers related to price and lead-time of mass customised garments. Paper IV discusses the benefits of making a digital configuration tool available online and how that could serve many more customers. Anderson (2006) refers to this ”democratisation of production tools,” that is mass customisation made available to the masses through the Internet and online configurators. Also, by the connection of supply and demand, which is one of the forces of the ”Long Tail” customer that will find the webpages that offer mass customisation concepts.

**Conclusion**

What components are then necessary for the customers to purchase customised garments? Customers need an interface that allows easy understanding of the customisation process. Piller et al. (Piller et al., 2003) suggest that it should be digital but seems to work equally well with a manual system. Huffman and Kahn (1998) even suggest that the characteristics of a manual system makes the customer feel more comfortable in the customisation process. So, for customer satisfaction it may not make any difference whether there is a digital customisation interface or if there is a manual customisation interface. However, if the company wants to reach out to more customers and facilitate the Long Tail economy (Anderson, 2006), the company should go for a digital one, which is also shown in Paper IV where an on-line system is able to cater almost nine times as many customers.

The service element is also a very important part of the customisation process. The assistance provided by the store staff and the possibility to customise a garment are regarded highest by the customers. Included in the
service element is also the experience of purchasing a customised garment. Gilmore and Pine (2007) suggested that a good buying experience is authentic, meaning that it feels genuine to buy the product in that particular store. The escapist type of experience that is offered to the customers includes actively involving the customer in the production process. Lead-time and price is not considered by the Knit on Demand customers as important aspects of the service element, rather contradictory to what you would learn as a logistician.

5.2 Supply chain processes and risk

One part of the original purpose was to develop a logistic solution for agility in customer relations. The term agility is used frequently within the logistic context and it is suggested that mass customised supply chain have a great deal of agility in them.

Research question II:
How does the processes in a supply chain for mass customised garments work?

Supply chain processes

The set up of a production system for mass customisation differs in many aspects from a set up of a system for mass production. One of the more important aspects is that orders are coming in randomly a one-piece flow and that there has to be available capacity in the system. Gupta and Benjafaar (2004) write that mass customisation systems work better if there is slack capacity in the system and from the project is seems like they are right. Since orders are coming sporadically and only one by one, it is difficult to schedule production.

The analysis of the results focuses on the part of the supply chain from manufacturer to customer (Figure 5.1) since yarns were taken from the existing inventory at Ivanhoe and no special yarns were ordered for the Knit on Demand garments.

Figure 5.1 Focus of the analysis.

Customer

The customer does not do anything except try on the size samples and tell the store staff what colour, model and accessories she prefers and how much she would like to have the size of the garment adjusted (Paper VI). The order is filled out by the store staff, hence reducing the risk of miscommunication
(Paper III) and also reducing the number of operations that the customer has to understand and perform. The customisation process uses on average 20 minutes of time.

**Retailer**
In the beginning of the project the retailer and the manufacturer was the same entity, but as SOMconcept took over the retail part of the project and the setup of the supply chain changed and complexity was added. Seen from a supply chain process perspective, what SOMconcept does is handle sales of the garment and the translation of the customer’s wishes to an order and sends that order to the manufacturer.

**Production**
The results from Paper VI indicated that the customisation and production lead-time for one garment would be between 120 to 301 minutes depending on material and model. A cotton garment would take a slightly longer time on average (206 minutes compared to 191 minutes) due to the washing process for cotton, which is not needed for wool. In the value stream mapping (Paper VI) the production time was clocked to 136,5 minutes production lead-time; in addition to that, the customer needs on average 20 minutes to customise a garment (Paper II). The calculated standard allowed minutes (SAM) for one mass customised knitted garment was 179 minutes; this is the time it is allowed to use in production. The higher SAM compared to the real throughput time is due to that mass customised garments need more control and attention from the production technicians. That was not expected and hence not accounted for in the simulation. The lead-times in Paper II were simulated for the originally intended shopping environment where the knitting machine was placed in the store, the customer customises the garment and also receives the garment once it is ready. Since the concept changed from having the knitting machine in the retail space to keeping it in the factory, 400 kilometres away from the store makes it difficult to compare the simulation and the actual outcome. However, the different steps of the design process and the production process remains similar, the customer enters the store and together with the store staff designs a garment. The order is then sent by e-mail to Ivanhoe who produces it and sends the garment back. The lead time differs, depending on the available capacity between one and four weeks. The production cost for a mass customised knitted garment is by the use of standard allowed minutes calculated to about the double of a standard item (Paper VI) in the knitting process, which is 260 SEK, roughly 25 percent higher than an equivalent standard garment.

**Decoupling point and postponement**
For customised garments it is not possible to keep products in stock and to have on-shelf availability, if one of each combinations would be available there would be around 100 million stock keeping units. Thus, an on-demand supply chain basically works on make to order principles (Rudberg and Wikner, 2004).
Knitwear yarns are kept in stock and when an order comes in the knitting machine is loaded with yarn and a garment is knitted. Inventory is held in the shape of yarns and accessories. For pants, inventory is held in the shape of cut pieces of fabrics in standard waist measurements but with longer legs that are cut to the right length and sewn when an order arrives. There were two knitting techniques available (paper I) in the project, Fully Fashion and Cut and Sew. They have different properties in respect to the decoupling point. Figure 5.2 illustrates the differences between the two knitting techniques.

In the Cut and Sew alternative, knitted panels could be knitted beforehand and kept in stock thus reducing the requirement for available knitting capacity after the decoupling point. On the other hand, the Fully Fashion technique produces less waste since the panels are knitted to the correct shape. In the Knit on Demand project a combination of the two techniques have been utilised.

Lean and agile
The purpose of the Knit on Demand project was to develop and test a new production solution for agility in customer relations. This suggests that there will be elements of agility as described by Christopher (2000). Agility is often mentioned together with the lean philosophies. According to literature, lean philosophies focus more on waste reduction and to create a flow that has the same pace as the customer orders (Liker, 2004). Agility on the other hand benefits from competing in a volatile environment (Christopher, 2000). So far so good, and combining the two concepts would then mean there is a supply chain that produces exactly what the customer wants, in the right quantities, when the customer wants it and at a profit. Mass customisation concepts do parts of that – they produce exactly what the customer wants, in the right quantities and when the customer wants it. Waste reduction, flow and producing at the pace of the customer, which are vital parts of lean production (Liker, 2004), are also evident in mass customisation (Paper V), which may suggest that such concepts are lean. Agile supply chains are integrated, virtual, network based and market-sensitive (Harrison and van Hoek, 2008). The Knit on Demand supply chain has elements of agility in it in the sense that it is market sensitive. Of course, the supply chain would benefit from a high level
of virtual integration between the producer and the retailer since it could
decrease information transfer related risks (Paper III).

**Supply chain risk management**
The number one reason for the reduction in risk is the postponement strategy
and that the customers are allowed to configure their own garments, which
supports earlier conclusions about postponement and risk (Feitzinger and Lee,
1996). The postponement strategy is an inherited part in the mass
customisation concept and thus, other supply chains for mass customised
garment can be expected to show the same characteristics. Shortage in capacity
was not initially expected to have significant impact on the concept, but in the
evaluation it turned out to have a very high impact. The reason is that the
retailer wants to give the customer a definite delivery date, but as long as the
manufacturer cannot dedicate capacity it will be difficult. Risk also increased
because of the added complexity of another partner in the supply chain. The
risk of a customer not understanding the concept is evident since it is a new
concept and not all customers can be expected to be fashion innovators and
have an interest or prior knowledge in designing garments. In the end, from a
risk management perspective the Knit on Demand project had a more positive
impact on the supply chain than initially expected. The risk of returned items is
lower than in a traditional supply chain, mass customisers usually have less
than one percent return rates (Paper IV).

The result of customers wish for one to two weeks of lead-time is that
capacity has to be booked before there is an actual order and that can be a little
counter intuitive even if it makes perfect sense. Also, the risk evaluation (Paper
III) showed that its capacity constraints in general have the highest risk and as
it turned out it was the capacity constraints that killed the project in the end.
Thus, the suggestion is that capacity is booked before there are any actual
orders.

**Conclusion**
To finally conclude how the processes in a supply chain for mass customised
garments work, a supply chain for mass customised garments requires that it is
possible to book capacity rather than products. It is more expensive due to the
higher level of control that is required in the manufacturing processes. It would
also benefit from a two-way information system that could let the retailer know
capacity availability and inventory levels. Supply chain related risks decreases in
a supply chain for mass customised garments compared to a supply chain for
mass products. A supply chain for mass customised garments have
components of both agility and lean philosophies in it and does not share
others such as network based and virtual integration. It may however benefit from a
higher level of IT-integration. What type of knitting technique that is used may
affect the supply chain. Cut and Sew has less operations after the decoupling
point and requires less capacity planning whereas Fully Fashion creates less
wasted material. Because of the postponement strategy return rates can be held
at a minimum; and since no garments are produced on forecast, there is no inventory of finished goods and hence there are no markdowns.

5.3 Technology and systems

One part of the purpose of the Knit on Demand project was to develop a production solution that includes a knitting machine, sewing machines and a design system.

Research question III:
What technical solutions are necessary to produce and sell customised garments?

**Knitting technology**

The considered knitting technology for the Knit on Demand project was Cut and Sew, Fully Fashion and Complete Garment. Complete Garment was early on taken away as an alternative due to the high costs of such an investment. It did however have some interesting possibilities for setting up a seamless supply chain. Since the original idea was to set up a system where the configurator was connected directly to the knitting machine the only manual activity would have been changing yarns between different garments. All the other processes would have been automatic. Since knitting would have been the only process, it would have had to be scheduled after the decoupling point, which would have made production planning less complex. For the other knitting technologies several post-knitting processes such as cutting and sewing had to be considered when scheduling production (paper VI).

Of the other knitting technologies, Cut and Sew and Fully Fashion, Cut and Sew is the less advanced knitting technique that offers the most-postponed solution since the shape of the garment can be decided after the knitting process. However, Cut and Sew has the highest waste of material and needs manual cutting, which is time consuming. It is not certain whether the benefit from the postponed decoupling point compensates for the increase in waste compared to other production methods (Paper IV).

Fully Fashion and Integral Knitting offer the possibility of knitting the panels in their final shape (Paper I). Less material is wasted and no cutting before sewing is needed. The drawback is that everything must be programmed in the knitting machine beforehand and that there has to be knitting capacity in connection to the customer order. Fully Fashion combined with cut and sew creates an elegant supply chain in terms of offering the customer large variety. Small changes to the garment can easily be made by hand before sewing the garment. In terms of production time there is no major differences between the knitting technologies. If only the efficient production time is calculated, production time is approximately three hours no matter what technique is used.
Configuration systems

For a successful configuration system, the following three things are needed according to Franke and Piller (Franke and Piller, 2002): 1) The core configuration software that the customer uses to customise the garments; 2) a feedback tool that visualizes the choices the customer has made; and 3) the analysis tool that translates the order into a production order. It certainly looks nice with a digital configuration tool and as seen in Paper IV, an online configuration tool can handle much more customers and utilise the Long Tail economy (Anderson, 2006). SOMconcept also has a digital configuration tool that they use for pants. A few of the customers (Paper V) also believed that a digital visualisation may help but they did not think it was necessary since the store staff is very friendly and helps out. By using samples of garments and swatches of fabrics the customers are able to visualise the end result good enough. Figure 5.3 shows what can be called the configuration tool in the SOMconcept store.

Figure 5.3. Configuration tool at SOMconcept.

Paper IV compares a manual configuration system compared to a digital ditto and concludes that the automatic system has the ability to cater to more people. Since the paper is built on a simulation, it is difficult to compare a digital system to a manual system from a customer perspective.

Information systems

In order for the order of a customised knitted garment to reach the manufacturer, an information system is needed. Da Silviera et al. (2001) point out the importance of integrated information systems as a success factor for mass customisation. In this project, a rather simple information technology was used; the solution is an Excel-sheet that is filled in by the shop assistant and then e-mailed to the manufacturer. It is perhaps not the most beautiful solution, but it does the job efficiently, is easy to understand and is reliable since e-mail systems seldomly break down. The drawback of such a simple solution is that it is a one-way solution. Information is only sent from the retailer to the manufacturer; therefore, it becomes problematic to share status on inventory levels and estimated lead-times. Also, the result of the risk evaluation (Paper II) showed that misunderstandings due to poor
communication had a high risk number. Harrison and van Hoek (2008), Christopher et al. (2004) and others write that communication is a vital part of supply chains with elements of agility, and this case is no exception.

**Conclusion**

The third research question aimed to answer what technical solution is necessary to produce and sell customised garments. It has in this thesis not been tested how the Knit on Demand project would work in an online environment. Customers have the possibility to customise pants online (www.somconcept.com), but data comes from those customers who have purchased garments in the physical store. However, one of the simulations (Paper IV) analysed the difference between how many customers could be served during a time period in a physical outlet compared to an online outlet. The simulation showed (Paper IV) that an online customisation service can cater to almost nine times as many customers as a physical outlet. Anderson (Anderson, 2006) has coined this as the ”Long Tail economy” and the idea is that via the Internet customers can easily access online stores for niche products. When it comes to mass customisation, the two driving forces is connection of supply and demand and the democratisation of production. The results from Paper V did however show that customers do not require a digitalised system to be satisfied.

For production purposes knitting machines and an information system is needed. The knitting machines can be of standard Fully Fashion or Cut and Sew type (Paper I and VI). They have the necessary capabilities to produce mass customised knitwear. For information sharing purposes an information flow that lets the retailer see production capacity and available raw material is necessary to reduce communication related risks to a minimum (Paper III).

5.4 Design

Design for mass customised garments differ a little bit from design of regular garments. For example, the garments have to flexible enough to cater to a wider range of body types than a regular garment and at the same time ensure manufacturability; therefore, research question IV was stated as follows:

*How can the design of mass customised garments be improved?*

The findings from Paper V and VII show that customers on average are adjusting the sizes of both knitwear and pants toward longer and thinner silhouettes. This knowledge can be used for improving the design of the garments but also for increasing the efficiency of the supply chain. The more processes that can be made simpler and postponed, then the better they are. Also, each operation that can be eliminated saves not preliminary time but the nuisance of scheduling production.

The design of the garment also affects the set up of the supply chain. For example the CODP can be placed differently and different customisation possibilities are allowed depending on if the garment is made with Fully
Fashion or Cut and Sew technology. Improved design of garments for mass customisation is closely linked to increased performance of the supply chain. If order fulfilment processes can be postponed to after the customer orders, decoupling point time and effort may be saved. From Paper II we find that there are a few post-knitting processes that have to be scheduled when facilitating Fully Fashion knitting technology. The result is that production capacity needs to be booked without any orders.

When a concept for mass customisation is built the product family architecture (Tseng and Jiao, 1996) can be used as a framework to construct the modules. Now, with the insights from the customisation process, having the data about the customers make it is possible to improve the design of both pants and knitwear in an iteration of the design process:

1. The first step when creating a product family architecture is to define the functional requirements of the garment. These are still rather basic garments, which means that their function is to protect the wearer from the elements and to portray some kind of image of the wearer. Here, it is very important to understand what the customer wants. Data from case studies such as the one presented in Paper VII could be helpful.

2. The second step is to identify design parameters of the garment and to choose the ones that are fulfilling the the functional requirements. Since about half of the customers wanted more design options (Paper V) the suggestion is that more design parameters are added. There is also space in the system since none of the knitwear customers experienced what Huffman and Kahn refer to as ”mass confusion” (1998) and half of the knitwear customers wanted more choice.

3. Step number three is to cluster the design parameters into building blocks. Since the average customer had a taller and thinner silhouette (Paper V and VII), one way of further improving the concept would be to make two sets of modules of the pants, one set that is longer and one shorter. By doing so material can be saved.

4. The fourth step is the granularity trade-off between options for customisation and what the supply chain can handle. Here is when the designer, the technician and the supply chain manager has to sit down, share the experiences from their part of the value stream and decide what is the optimal trade-off between the three of them. Da Silviera et al. (2001) point out the importance of sharing knowledge between the partners in the value chain when pursuing mass customisation. In this case (Paper I), a trade-off was made between the design of a garment, the decoupling point and the knitting technique.

The aim is to increase the customisation options and to move as many of the expensive processes as possible to after the decoupling point. The processes itself does not necessarily have to be expensive but the result of the process might be, for example, it is not expensive to sew a pair of jeans, but the result of sewing the wrong pair of jeans is expensive. For knitwear, most of the expensive processes are already downstreams from the decoupling point
whereas for pants some cutting is done upstreams from the decoupling point and some are done downstreams from the decoupling point.

It is always a trade-off between different aspects when developing a business concept; one of the trade-offs that had to be made is between nice looks of the garment and flexibility of the supply chain processes (Paper I). The Fully Fashion knitting technique offers the possibility to have less bulky seams compared to the Cut and Sew knitting technique (Figure 5.4), but Cut and Sew is more flexible.

![Fully Fashion and Cut & Sew seams comparison](image)

**Figure 5.4 Illustration of the difference between Fully Fashion seams and Cut and Sew seams.**

The possibility to have a set up with only cutting and sewing after the decoupling point would be beneficial from a supply chain perspective. Knitted panels could be kept in stock and hence lead-times from customer order to fulfilment could be shorter. With such a solution the knitted garment would have a slightly bulkier look since some of the seams would have to be made with an overlock sewing machine rather than with a one-needle machine.

**Conclusion**

In brief, the answer to how design for mass customised garments can be improved is that it depends very much on what concept the customer is aiming for. Most customers made size adjustments on the garments; it might therefore be useful to develop more size alternatives and perhaps customisation platforms that build solely on size adjustments and do not offer any customisation of model and colour. The tradeoff between the beauty of the garment design and the beauty of the supply chain design is difficult but necessary in this case.

**5.5 Overall research question**

In order to briefly answer the overall research question, which was: *How does a responsive supply chain for mass customised garments work?* A supply chain for mass customised garments is more expensive than a regular supply chain. The
manufacturing cost of a customised knitted garment is about 25 percent higher than for an equivalent standard garment. That corresponds well with what Alvan and Ayden (2009) wrote, that productivity in mass customisation systems decreases and increased cost is inevitable. Increase in cost is mostly due to the need for more control in the knitting process (Paper I & VI). Manufacturing lead-times vary between two and three hours depending on material and design (Paper II) Da Silveira et al. (2001) concluded that a vital part of mass customisation systems are integration between supply chain partners. The results from Paper III also shows that risks could be reduced if a two-way information system that allows the retailer to see inventory levels and available production capacity at the manufacturer is implemented. Risks in a supply chain for mass customised products are on average lower than risks in a supply chain for equivalent mass products and it is mostly due to the postponement strategy (Paper III). Customers are central in any supply chain and the results in Paper V showed that customers cared mostly about fit, quality and the service in the store (Paper V) and that lead-time and price were secondary. The customers liked the interaction process with the store staff and did not require a digitalised system to feel secure with the design. This conclusion is supported by Huffman and Kahn (1998) who claim that the characteristics of a manual design system is preferred by customers. However, it would benefit the concept to have a digitalised system in an online environment (Paper IV) in order to facilitate the Long Tail economy (Anderson, 2006). Paper V and Paper VII also showed that most of the customers that shop mass customised garments at SOMconcept were taller and thinner than the average fashion consumer. Paper V showed that half of the customers who chose to change the size of the garments had sizes that were outside any standard size. That basically means that they would not be able to buy ready made garments that fit them at all.

In conclusion, this supply chain for mass customised garments worked fine and the customers benefit from it since it fulfills an earlier desire that was not able to be fulfilled – having garments that fit. Most of the success factors (Da Silveira et al., 2001) for a supply chain for mass customised products are fulfilled except for ”value chain must be ready”. The mass customised products had to compete against mass products about production capacity and usually mass products won. The Knit on Demand supply chain had to stop in December 2010 due to capacity constraints.
6 Discussion

This chapter discusses the answers to the research questions in relation to the fashion business in general.

The thesis started by presenting the fashion business in general and the problems it has due to its mechanism and dynamics. This chapter sets the results of the thesis, and the analysis of the results in relation to the original model and how it could help to fulfil the purpose of the Knit on Demand project. Moreover, it discusses how the results from the thesis can contribute to the fashion business as a whole. Figure 6.1 illustrates where the result from the thesis fits into the general model of the fashion world.

![Diagram showing the fashion business model](image)

Figure 6.1 Where the results from the thesis fit into the model of the fashion business.

6.1 Customers

The purchase of a mass customised garment differs from the purchase of an off-the-shelf garment. Since it is made to order, the customer has to wait for the garment, up to several weeks, before he or she can try it out and make the final judgement. In an ordinary retail outlet the try-on is instant and the customer walks out of the store with the product. The customisation process and the anticipation in the wait for the final result makes the customer more involved with a mass customised garment than a standard off-the-shelf garment. Also, since the customer spends more time in the store with the staff, they will know each other on a different level. Moreover, the integration of the customer in the value chain does not stop at the retailer. The manufacturer also feels more connected with the customer since they see the names and the sizes of the customers. Even though they do not meet each other personally they still are interconnected on a higher level. It would be fair to say that a supply chain for mass customised garments is less anonymous than a supply chain for mass products.

Since the Knit on Demand concept was not tested in an online environment, it is not possible to conclude anything about whether digital
visualisation is necessary for successful customisation or not, more than that the customers did not think it would help them in the customisation process (Paper V) and that an online configurator would reach more customers. Most customers of mass customised garments are making size adjustments on their garments and a significant amount of them are adjusting towards longer and thinner silhouettes. These are niche customers that cannot find the size they prefer in a traditional retail outlet. Such niche customers benefit from the Long Tail economy (Anderson, 2006). In the Knit on Demand concept the first of the three powers of the Long Tail has been utilised, the democratisation of production tools, which makes customisation of garments available to the masses. However, to truly utilise the Long Tail economy as an online configurator and the use of blogs and online advertisement would connect supply and demand, which is the third power of the Long Tail, and make the concept more available to the niche customers. Moreover, successful mass customisers are available online and have an interface that allows customers to configure their products, why it may be so that in order to have a successful mass customisation business there should be a virtual connection to the configurator, something also suggested by Franke and Piller (2002). It may not be necessary, but it helps.

The experience of buying a customised garment is central for many customers. One part of the experience is the earlier mentioned involvement in the production process and the de-anonymization of the supply chain. Gilmore and Pine (2007) claim that the authenticity of a business concept is vital for success in business. Perhaps more important in businesses with strong brand images such as the fashion business than in others such as in the hardware (hammers and screws) business. The four realms of an experience, esthetic, escapist, entertainment and educational (Gilmore and Pine, 2007), can be used to create an experience around any business concept. In a mass customisation concept the customer may feel she is truly the designer of a garment even if she only chooses between a number of pre-engineered modules. One preconceived though that I, the author, had about the customers was that lead-times and prices were important aspects of a purchase. Surprisingly the customers did not bother about either price or lead-time. It may even be suggested that waiting time and the higher price added value to the product, like when purchasing a Ferrari. The insights regarding customers and what they want can be applied to the conventional fashion business. The experience around creating a unique garment may perhaps be translated into an experience of creating a personal style out of the garments available in the store and in that way adding more value to the retail concept.

6.2 Supply chain and risk

One part of the success with companies like Zara (Ghemawat and Nueno, 2003) and Benetton (Mantle, 2000) is that their information systems give instant access to point of sales data and inventory levels. These systems are essential for the relationship with their particular customers. For Zara’s and Benetton’s supply chain set up it is perhaps only necessary with a one-way
information system that allows them to see what is missing on the shelf and how much is sold of each garment. It is likely not in the interest of the retail outlet to know how much there is in inventory in the central warehouse. Even if they did know, the question is how they would use the information. For mass customisation systems these types of systems are necessary as well but with the difference that the retailer needs to see the inventory levels at the manufacturers so that they do not sell garments that cannot be produced. In that sense, the virtual and integrated parts of agility (Harrison and van Hoek, 2008) would help and further reduce communication related risks in the supply chain.

The target with creating a responsive supply chain is to increase the performance of the supply chain. Sell-through percentage, lost sales and service level are common key performance indicators in fashion supply chains. Mass customisation would in theory affect them as follows:

**Sell-through percentage** – Since mass customised garments are produced on order there will be no inventory for finished goods, hence no need for markdowns at the end of the season. Sometimes markdowns are used as marketing strategies, but that is not considered in this thesis. As a key performance indicator the sell-through percentage may be unnecessary for mass customisation business.

**Lost sales** – Lost sales are difficult to measure but it is related to the service level in the sense of shelf availability. Lost sales are measured on how many customers that are able to find their preference in the store and since a mass customisation concept, even one as simple as Knit on Demand, offers close to 100 million combinations of garments, more customers would be able to find their garment of choice and thus decreasing lost sales.

**Service level** – Mass customisation concepts would in theory have a higher service level than mass products since products are knitted on order and close to one hundred percent of the orders are delivered. However, if measuring the service level at the retailer for mass customised garment you also have zero percent shelf availability, which is not very good but an inherited part of a mass customisation concept. Instead it is suggested that the service level of inventory is measured, this gives a better view of the supply chain performance.

**Risk management**

Paper IV showed that a supply chain for mass customised garments have a lower risk than a supply chain for mass garments. The risk reduction is connected to the postponement strategy and to the speculation strategy since capacity has to be booked, and material bought on speculation. However, a supply chain for mass customised garments could benefit from a higher level of risk sharing, which at the same time means a higher level of sharing profits. In the Knit on Demand supply chain risks were shared as in any textile supply chain and also profits; the manufacturer produces and sells a garment to the retailer who marks up the garment with a factor two to three and sells it to the customer. In an ideal supply chain for mass customised garments the price to the customer would be the same but profit would be shared more equally since
the manufacturer is taking a larger risk. The manufacturer holds booked capacity and inventory that would have been kept at the retailer in the shape of ready made garments in a supply chain for mass products. One of the problems with the postponement strategy in the Knit on Demand supply chain is that the inventory and the retailer is physically separated and the distance between them is 400 kilometres. The result is that the store staff cannot see what is in stock and there is a risk that they will sell garments that cannot be produced because the factory is out of that particular yarn.

Within the fashion distance shopping industry return rates can be up to 40 percent (Norek, 2002). Among mass customisers the return rates are low, as low as one percent (Paper VI) and insights from that part of the fashion industry can be applied on the distance shopping industry thus decreasing return rates. Also, since mass customisers do not have to put abundant stock on sale, the waste of overproduction is also removed. In that sense mass customisation concepts have elements of lean production.

6.3 Technology and systems

One of the initial ideas in the Knit on Demand project was to analyse how complete garment technology could be used to change the set up of a fashion supply chain. If Complete Garment technology could knit, complete garments would have been possible to set up the system in a store with a connected digital configuration system. However, even if technology makes it possible to knit complete garments it is likely that there has to be some post processes such as cutting and sewing to get the right finish of the garment. The collar for example cannot be knitted stretchy enough on a two-bed knitting machine because of the properties of the knitting machine. It requires a four-bed machine if complete garment technology is to be used. One knitting machine manufacturer that offers four-bed technology is Shima Seiki (Shima Seiki, 2011). A four-bed machine would be able to produce enough variants to cater to the needs of most customers. Integrated with a configuration system but also together with a point of sales system the technology could cater to two types of customers (Figure 6.2).
The first type, customers who prefer to have their garments customised and want to configure the garments themselves, can do that through digital interface online or come to a store and get assistance from the store staff. The second type of customers could be fashion companies that want fast replenishment of garments that are running out of stock. A connection from the point of sales (POS) system directly to the knitting machine, with some manual control valve between, could help to facilitate Complete Garment technology, not only for mass customisation but also for mass products.

6.4 Design

There are basically two ways to develop design for mass customised garments, one is to make one set of customisation options for customers who only want a garment that fits them perfectly. The other is to develop customisation tools for those customers who want more options in style and colour.

Size adjustments

Most customers changed the size of their garment (Paper V and VII) and about half of the customers wished for more customisation options. It is fair to guess that customers who were happy with the customisation possibilities would be happy if they could have standard garments made to measure, thus leaving customisation of style and colour out. By doing so, customisation of measurements could perhaps be employed in the more mass product oriented businesses. The benefit of such set up could result in decreased return rates, increased sell-through percentage and decreased lost sales. Such set up could make it easier also for the manufacturer since there would be less complexity and it allows for more automatisation of manufacturing processes and thus cheaper garments and faster delivery.
Design adjustments
The other half of the customers who wanted more customisation options require a more flexible set up, one that has a lower grade of automatisation than the current case. For those customers the concept could be taken one step back technology-wise and to facilitate Cut and Sew techniques that are more simple but on the other hand more flexible after the decoupling point. Figure 6.3 illustrates a possible design solution for such Cut and Sew garments.

![Figure 6.3 Panels are knitted and then cut to shapes to make up a garment.](image)

6.5 Generalisation and validity of results
The thesis presents and analyses results from the Knit on Demand concept, from SOMconcept’s customisation of trousers and from Shima Seiki’s ordermade system. The results from Knit on Demand and SOMconcept’s trousers build on data from real customers in a real environment who spend real money. This contributes to make the results more valid than for example a simulation could. The Shima Seiki Ordermade simulation was done using input data from Shima Seiki and from the Knit on Demand concept where data from Shima Seiki was missing. This makes the study less valid. However, the data that was used to patch the simulation was knitwear production data such as production lead-times.

An action research project or a case study is always hard to generalize since it studies one or a few objects and this case is no exception. The findings in this thesis are findings from three mass customisation concepts and there are many similarities between them but it would be very bold to claim that what is written here is the absolute truth. By matching the results against existing theories conclusions can be made (Winter, 1989).

In the same way that action research and case studies are difficult to generalise, they are also difficult to replicate. Therefore the reliability of the results are difficult to prove. For this type of research however, the researcher has to accept that type of shortcomings (Yin, 2009). For generalisation purposes standard operational measurements have been used.
7 Conclusion and further research

This chapter, Conclusions and further research, concludes the thesis and suggests what will be the next step in research.

7.1 Conclusion

The purpose of the Knit on Demand project was to develop and test a new production and logistic solution for agility in customer relations. The idea was that sell-through percentage and service level would increase and lost sales would decrease, hence decreasing the the gap between the retailers assortment and customer’s expectations (Figure 1.1). A solution for mass customised knitted garments was developed in collaboration with SOMconcept and Ivanhoe AB and tested during 16 months in SOMconcept’s store. Additionally customisation of trousers and a Shima Seiki’s ordermade system were analysed. These are the conclusions:

For customer satisfaction it does not seem like there has to be a digital interface for customisation of the products. Some customers thought it might help, but the assistance from the store staff was enough. The store staff would be better in listening to the customer and to present the attributes of a garment than a digital system would. However, a digital system that is made available online would be more efficient and able to handle more customers per time unit and to reach out to more customers and thus facilitating the Long Tail economy. Also by making it available online one could get more “mass” into mass customisation.

Customers were surprisingly not bothered about long lead-times (< 3 weeks) and high price (< 1600 SEK). Instead they saw the service provided in the store, the quality of the arment and the configuration possibilities as key factors. The sense of being actively involved in the production of a unique garment, a one-off just for that customer, builds the authenticity of a concept like Knit on Demand.

The highest supply chain risk for the project and also the reason why it had to be cancelled is capacity constraints. Already in the initial phase of the project capacity constraints was considered to have a high risk. Being able to book capacity in advance, before there are any customer orders, is necessary for being able to keep lead-time promises. Because even though customers did not bother about long lead-times, it is always nice to be able to keep promises. A supply chain for mass customised products also requires a two-way information sharing solution. Upstreams that the solution should deliver customer orders and customer details such as biometrics for future orders. Downstreams that the solution should deliver at least information about inventory levels and capacity availability, so that the retailer always knows what is in stock and thus keeping the customer from configuring garments that cannot be manufactured. The risk of returned items in supply chains for mass customised fashion is low, as low as under one percent. The reason for that is mainly that customer have their garments made to measure.

Supply chains for mass customised garments have elements of both lean philosophies and agility. From a lean perspective waste in the shape of mark
downs and returns are decreased since only what is ordered is produced. From an agility perspective the Knit on Demand supply chain is market sensitive; it would however gain from more integration and if the Long Tail economy is to be utilised a dash of virtual integration would help bring customers into the system.

Different knitting techniques will offer different possibilities for supply chain set up and for customisation options. It depends on what customers the supply chain wants to address. If it wants to attract more design-oriented customers, a Cut and Sew set up would be better because it does not require extensive programming of a knitting machine as a Fully Fashion set up for each design option. Fully Fashion on the other hand, with only size options, would be better for those customers who only want a garment that fits them. That would decrease the manufacturing cost of a customised garment, which in this supply chain was about 25 percent higher than the price of an off-the-shelf garment.

Mass customised garments are not for everybody but for the customers that either have a body that does not fit the standards or want to create a garment with a unique expression.

7.2 Future research

For further research of a number of papers with their basis in the conclusion from each topic, customers, supply chain and risk, technology and systems and design, are suggested:

Customers
Title: Customer involvement and the de-anonymisation of supply chains.
Customers are more involved in the purchase of a customised garment than in the purchase of an off-the-shelf garment. The customers enjoy the involvement and experience that they are a part of the production process. Since humans generally are willing to pay money for things they enjoy, it may be suggested that opening up the supply chain would be value adding in some sense and thus something that a company could charge money for. Therefore, a marketing concept that builds on the de-anonymisation of a supply chain needs to be developed and tested. Figure 7.1 illustrates a hangtag for a customised garment that shows the involved people in the chain and therefore makes it more transparent.
Technology and systems
Title: Seamless supply chains with 3D technology.
In textile and fashion, the Complete/Whole Garment knitting technique makes seamless supply chains where orders are sent directly from the POS systems into the knitting machine possible with as little human interference as possible, at least in theory. There are also applications of other 3D technologies in fashion such as 3D printing. It makes it possible to manufacture most products on-demand and this paper would investigate what systems are available and how well these systems can be integrated to create a seamless supply chain.

Supply chain and risk
Title: Application of insights from mass customisation to increase supply chain performance for distance shopping industries.
Companies within the mass customisation generally have low return rates and the traditional distance shopping industry suffers from high return rates. The idea is to apply insight from mass customisation on the distance shopping supply chains and to analyse how return rates can be decreased. Since the distance shopping companies are selling ready to wear garments the possibilities to customise products are limited. However, the supply chain processes such as delivery and other services can perhaps be customised to fit the individual needs of the customers.

Design
Title: Beyond customisation.
“Design your own...” is very often used to attract the customers to mass customisation concepts. However, most of the products are standard products that the customers are allowed to change in a number of predetermined ways. Design however is something more than just choosing the colour or changing
the length of the arms, it also involves changing the silhouette and the whole expression of the garment. The idea is to create the basis for a new type of design and manufacturing that allows true own design for everybody.
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Industrielle Betriebswirtschaftslehre der Technische Universität München.


Paper I


An earlier version of this paper was presented on the Textile Future conference at North Carolina State University 2008 and included in the conference proceedings.
Design and development of Mass Customized Knitted Garments

Authors: Jonas Larsson and Pia Mouwitz

An earlier version of this paper was published on the Presented on Textile Future conference, North Carolina State University 2008 and included in the conference proceedings.

Abstract

Even though the assortment in many stores widely exceeds most customer needs, customers still want more. A mass producer can only handle a certain amount of stock keeping units before the variety becomes unmanageable and will eventually lead to overstocking and unwanted markdowns. Mass customisation is a concept that builds on people’s increased wish for variety but instead of speculating about what the customer may want the customer designs, or configures the product themselves. Knit on Demand is a research project in which a supply chain for mass customised knitwear has been developed and tested. One part of developing the supply chain was to design the collection of garments and the purpose of this paper is to describe the results of that design process. In order to reach the target of any mass customizer, which is offering a larger variety of design options at almost mass production price a module-based design has been used. The result was a system that builds on one base module available in size extra small to XXXL and that can be customised in colour and shape.

Keywords: Mass customisation, design for mass customisation, knitwear, platform design

Introduction

Customers increasingly demand a greater variety in their selection and to solve the customers’ different needs, companies started to offer a greater variety in products. In the early 1970s, there were five different running shoes to choose from; in 1988, that number had increased to 285 (Luximon, 2003) and in 2008 one single on-line retailer offered more than 550 running shoes (Footlocker.com, 2008). A mass producer can only offer that many variants (stock keeping units) of a product before the variety becomes unmanageable and an increase in variety inevitably leads over-stocking and price markdowns at the end of the season. But since there has long been a demand from customers for greater variety, mostly due to size issues or design issues related to size (Bickle et al., 1995, Shim and Kotsiopulos, 1991, WGSN.com, 2002), a few companies have discovered this niche market and offers customers mass customised products. Mass customisation as a production paradigm has evolved from the mass production era and the essence of it is customer involvement. According to Duray (2002) the two identifiers for mass
customisation is one; customer involvement in the design process, and two; mass, to gain scale volumes through modularity. Modularity keeps the number of options down and allows for repetitive manufacturing. By bringing the customer close to the company, actually all the way to the drawing table, a supply chain should, at least in theory, be able to respond fast and accurately to true customer demand and increase profitability. So far, however, the benefits of customer integration has not been proven (Piller et al., 2004). With the emergence of the Internet companies are able to reach enough customers to be profitable (Da Silveira et al., 2001, Anderson, 2006). Anderson (2006) describes this as facilitating the “long tail economy” that has emerged with the Internet. Mass customisation begins in understanding each customer’s requirements and ends in delivering one unique product to a unique customer. The process includes design, marketing, production, purchasing, logistics, etc. (Tseng and Jiao, 1996). In order do this successfully three aspects have to be considered: time to market, variety and economy of scale (Tseng and Jiao, 1999). Duray (2002) claims that the key aspects of mass customisation is involvement and modularity.

Both Tseng and Jiao’s (1999) and Duray’s (2002) description of key aspects include the design element and how build modules that let the customer be involved. Customers become involved in a purchase of a mass customised product because they have needs that the mass products do not fulfil. Since the customer is involved in the design of the garment the system has to be easily understood to avoid confusion (Huffman and Kahn, 1998), offer enough flexibility for the customer to be satisfied and it has to build on modules to gain economies of scale in production (Pine et al., 1993).

Focus topic: Design
Design is according to Merriam-Webster’s Dictionary described as:

“to create, fashion, execute, or construct according to plan”

When a collection is started, it should be very clear whom the design is for, according to Richard Sorger & Jenny Udale (2006). They describe various factors from a designer’s view, depending on what kind of company the garments are supposed to represent: haute couture, ready to wear, luxury super brands, mid-level brands and designers, independent designer labels, casual and sportswear brands, high street (chain stores), and supermarkets. The type of garment is another key issue for designers: casual wear, jeans wear, sportswear, swimwear, underwear, evening wear, tailoring, knitwear or accessories. Design for mass customisation aims to provide customer satisfaction with customization and increased variety without corresponding increase in lead time and cost (Tseng and Jiao, 1996).

Focus case: Knit on Demand
Knit on Demand is a research project at the Swedish School of Textiles in collaboration with a knitwear producer in the south of Sweden, Ivanhoe AB,
and a retailer of tailored fashion in Stockholm, SOMconcept AB. The purpose of the project was to develop and test a new production and logistic solution for agility in customer relations. To fulfil that purpose from a design development point of view the following purpose with this paper is stated:

The purpose of this paper is to describe the design and development of the collection of mass customised garments.

Theoretical framework

Design for mass customisation

Design for mass customisation differs from design for mass products. Where a designer of a traditional collection considers aspects like price, what the garment will represent and colour ways (Udale and Sorger, 2006), a designer of a collection of mass customised garments has to add the flexibility dimension. In order to understand what type of product that is going to be manufactured and the product’s characteristics. Gilmore and Pine (1997) has defined four types of mass customisation, these are adaptive-, cosmetic-, transparent- and collaborative customisation (Figure 1).

![Figure 1. Four faces of mass customisation](image)

Adaptive customisation: The company provides the customer with standard parts and lets the customer do the customisation. Lego is a good example of adaptive customisation.

Cosmetic customisation: Offer a standard product but with different packaging options, e.g., some breweries offer customized labels on their beer.

Transparent customisation: No changes in the appearance of the product but the properties are changed. A pair of glasses looks the same no matter what the strength.

Collaborative customisation: The highest level of customisation requires a close dialogue with the customer in which the customer articulates his or her needs. Examples of this are tailored product such as shirts, shoes, and suits. It is often is regarded by purists as the true type of customisation (Da Silveira, et al., 2001).
Design for mass customisation aims to provide customer satisfaction with customization and increased variety without corresponding increase in lead time and cost (Tseng and Jiao, 1996). To create a system for mass customisation is to find the balance between increased variety, cost, and lead times. That includes three major technical challenges: reusability, product platform and integrated product development (Tseng and Jiao, 1999).

**Reusability**

Supply chains for mass customised products are typically make to order supply chain (Rudberg and Wikner, 2004). Modularity is key to efficiency in many make to order supply chains keeping the number of stock keeping units down and uses economies of scale. It is necessary since mass customisation decreases productivity and increases costs (Alvan and Aydin, 2009). One of the key enablers for mass customisation is the ability to identify and exploit similarities in design and manufacturing and to reuse these methods and components in production as well as in supplier base and logistics. Then, those similarities are built into product family architecture in order to rationalize production and to ensure quality and lead-times. These “building blocks” that constitute the basis for the design and manufacturing are then assembled in individualized products (Tseng and Jiao, 1996). Modularity has many similarities with platform design. Muffatto and Roveda (2002) describes a platform design as “…a set of subsystems and interfaces intentionally planned and developed to form a common structure from which a stream of derivative products can be efficiently developed and produced”.

Central for make to order supply chain is the placement of the decoupling point (Rudberg and Wikner, 2004). The design of a mass customisation system, available production technology and supply chain processes are closely related to the decoupling point. Before the decoupling point inventory is mostly held in the shape of raw material such as yarns and fabrics and nothing is produced unless there is an actual customer order.

**Product platform**

Tseng and Jiao (1996) has suggested a framework for developing mass customised products, which they call product family architecture (PFA). The basis of the PFA is selected upon customers’ needs, repeatability in design and order fulfilment, the ease of configuration, and the appropriate aggregation level. The aggregation level is on which level the building blocks are assembled. For example, in knitwear the aggregation level is on different levels depending on what knitting technique is used. If the aggregation level is too low there will be too many building blocks and the design process as well as configuration and fulfilment processes will be too complicated. If the aggregation level is too high then there might not be enough choices for the customer. Tseng and Jiao (2003) has defined two types of problems associated with optimising the level customisation. The first problem is associated with alternative selection, which is to choose the most appropriate variants for the concept. The second problem is determining the optimal settings for the design parameters, more
specifically, how much shall the customer be allowed to change. One method of optimising the degree of customisation is to use Sami and Yasser’s (2009) magnitude of customisation (MOC) model that numerically measures the level of customisation in a mass customisation system. It is a measure of the percentage of customisation of a product. If a product is one hundred customisable the customer may change every aspect of the garment.

Tseng and Jiao (1996) defined a framework for formulating a product family architecture (PFA) for mass customised products:

1. Functional requirement of the garments - The first step is to define the functional requirements of the garments.
2. Identifying design parameters - Design parameters should be chosen based on their ability to fulfil the functional requirements.
3. Cluster the design parameters into building blocks - When the design parameters are identified they should be clustered into groups and translated into modules
4. Granularity trade-off - The trade-off between the options for customisation and what the supply chain and customers can handle. There is also a limit on how many choices a customer is able to process without confusion (Huffman and Kahn, 1998).

The basis of a PFA is selected upon customers’ needs, repeatability in design and order fulfilment, the ease of configuration, and the appropriate aggregation level. The aggregation level is on which level the building blocks are assembled. For the ease of selling the mass customized products, it is necessary to provide a structure for describing the product family architecture. The structure has to describe the way the building blocks are organized so the company can fulfil consumer needs. A successful PFA is based on concurrent engineering, optimal commonality, configuration rules, product line taxonomy, and economic evaluation (Tseng and Du, 1998).

**Knitting technologies**

A few flatbed-knitting technologies has been considered in the Knit on Demand project (Figure 2).
Cut and sew is the oldest and simplest method, the technique is built on knitted panels that are cut according to a pattern, and stitched together. Cut and sew’s successor Fully Fashion, has the ability to knit the panels into desired shape directly in the machine. Integral knitting is a further development of Fully Fashion and can add details such as pockets (Spencer, 2001). Complete garment technique, knits the entire garment in one piece in the knitting machine and (Choi and Powell, 2005).
Method

The core idea of action research is that the researcher does not limit to observing an object but actively engages in the process of developing the object and the knowledge connected to the object. In action research the process of change and development is the main research focus and authors try to contribute both to the development of an organisation and to the development of science (Näslund, 2002). Winter (1989) writes that good action research includes attacking the studied object from several directions. It is so that some problems require a multitude of research methods to find a solution. The problem with action research is that there is no established framework for evaluating the results from action research (Näslund, 2002). Näslund et.al (2006) reflects that the goal of action research is not to find the cause and effect relations nor to generalise, but rather to understand and develop the processes in joint learning within the context studied. McNiff and Whitehead (2002) also focus more on the learning in the organisation than on describing cause and effect relations. It is suggested that action research methods require different presentation techniques than what is traditionally found. A report of an action research process would only be a linguistic explanation of the studied object, whereas a product or a film from the research process could explain the process better (McNiff and Whitehead, 2002). The methodology of action research can be described as an iterative loop where the theories are matched against ideas and reality in order to come up with a final solution. McNiff and Whitehead explain it as a Plan Act Observe Reflect (PAOR) – loop. This methodology has been used in the Knit on Demand project and is illustrated in figure 3.

![Figure 3. Development phases of the Knit on Demand-project](attachment:figure3.png)

The project spanned over four and a half years, where three years were development time and one and a half year was testing the concept in the retail outlet. This paper focuses on the three years of developing the design of the garments. The development was done in three phases (figure 3), in the first phase complete garment technology connected to a digitalized design system was evaluated but found too expensive so the project team had to disregard from that technology even though it had great supply chain implications such as three hour response time. In the second phase a Smart retail system that
built on radio frequency identification (RFID) was tested but found insufficient to the purpose of the project. The final try, and also the one that succeeded was the development the system that builds on Fully fashion technology. The development of the system took a little more than one year and included several loops back and forth before the system was found good enough to present to the customers. Much time were spent on getting the style of the garment right so that it fit SOMconcept’s image. Additionally, data from a case study of the Knit on Demand supply chain has been used. The case study was conducted using the “value stream mapping tool” (Hines and Rich, 1997).

Result: Customisation of flat knitted garments

The purpose of this paper is to describe the design and development of the collection of mass customised garments in order to fulfil the purpose of the Knit on Demand project, which was to develop and test a new production and logistic solution for agility in customer relations. These are the results of the design development.

Product Family Architecture for Knitted Garments

In order to fulfil the customer’s wish, the functional requirements for the garment have to be stated and translated into the product. For any type of knitted garments the functional requirements are to protect the wearer from the elements and sometimes to show what class in society the wearer belongs to. For a customised knitted garment the functional requirements would be to be able to get the right size and to make a personalised design. Table 1 explains the different functional requirements.

Table 1. Functional requirements

<table>
<thead>
<tr>
<th>1st level</th>
<th>2nd level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fit</strong></td>
<td>Arm length</td>
</tr>
<tr>
<td></td>
<td>Waist width</td>
</tr>
<tr>
<td></td>
<td>Body length</td>
</tr>
<tr>
<td></td>
<td>Shoulder width</td>
</tr>
<tr>
<td></td>
<td>Armpit size</td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td>Colour</td>
</tr>
<tr>
<td></td>
<td>Material</td>
</tr>
<tr>
<td></td>
<td>Model</td>
</tr>
</tbody>
</table>
Design parameters
The design parameters are chosen on their ability to fulfil the functional requirements, which are providing the customer protection from the elements and to help the customer looking good (Table 2).

Table 2. Design parameters of the garments

<table>
<thead>
<tr>
<th>Design parameter</th>
<th>1st level alternatives</th>
<th>2nd level alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>V-neck</td>
<td>Round-neck</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Turtle neck</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cardigan</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Deep v-neck</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slipover</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Two colour striped roundneck</td>
</tr>
<tr>
<td>Design</td>
<td>Fabric</td>
<td>Cotton</td>
</tr>
<tr>
<td></td>
<td>Colour</td>
<td>12 colours</td>
</tr>
<tr>
<td></td>
<td>Contrast stitching, collar</td>
<td>12 colours</td>
</tr>
<tr>
<td></td>
<td>Contrast stitching, cuff</td>
<td>12 colours</td>
</tr>
<tr>
<td></td>
<td>Stripes</td>
<td>2 stripes 12 colours</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 stripes 12 colours</td>
</tr>
<tr>
<td></td>
<td>Buttons</td>
<td>Colour</td>
</tr>
<tr>
<td></td>
<td>Size adjustment</td>
<td>XS-XXXL</td>
</tr>
<tr>
<td></td>
<td>Sleeve length</td>
<td>± 8 cm</td>
</tr>
<tr>
<td></td>
<td>Body length</td>
<td>± 8 cm</td>
</tr>
<tr>
<td></td>
<td>Individual fitting (waist etc)</td>
<td>∞</td>
</tr>
</tbody>
</table>

Clustering design parameters
Before clustering the design parameters the production technology has to be decided since different knitting technologies has different capabilities. Fully fashion for example can knit panels into the right shape, cut and sew cannot. Here, many trade offs has to be made regarding economy, lead-times, appearance of the garment, customisability, modularity etc. One trade off was done early on in the project and that was not to use complete garment technology since the investment in a machine with the additional digitalised design-system was considered too expensive. Left was a trade off between fully fashion- and cut and sew technology. Figure 4 illustrates the difference in appearance between fully fashion and cut and sew.
Figure 4 Difference in appearance between fully fashion and cut and sew

The left picture illustrates the characteristic patterns when the loops are hung over to create the shape knitted panels. Fully fashion does not need to be cut before sewing and the edges of the garment pieces are already fixed. Therefore the linking of the garment pieces can be done with a one-needle machine resulting in a lighter seam.

In Figure 5, the different design parameters are clustered into the modules of the garment. Since the garment will be module-based there will be a number of pre-defined limitations that cannot be changed. If those parameters could be changed, the lead-time, quality, and cost of the garment could not be guaranteed. It is important to limit the change possibilities because some changes, such as the size of the armpit hole, might have unmanageable consequences on the rest of the garment.

Figure 5 Design and functional parameters clustered into modules

Granularity trade off

Due to productivity and quality reasons it is not possible to let the customer change every aspect of a garment. In this concept the customer is allowed to have the garment made to measure, choose colours and choose contrasting fabrics. Only smaller changes in the silhouette of the garment is allowed, for example, the waist of the garments may be changed to fit customers with big shoulders and arms.
The concept

Figure 6 illustrates the six different models that are offered to the customer. Each model builds on the same base modules, which are the body and the arms that are lengthened, shortened, narrowed, or widened depending on the customer’s preferences. To create the different models the neck hole is cut to the right shape and a collar is attached to the garment.

Figure 6. Different models offered to the customer

Figure 7 illustrates one of the garments from the concept.
Figure 7. A V-neck garment in size medium with contrasting fabric in the collar (not visible)

Production lead-times

Figure 8 shows the production process with its corresponding lead-time, set-up time and standard allowed minutes (SAM). A standard allowed minute is the calculated time for each individual production step, it is used to allocate capacity and to calculate the cost of production.

Figure 8. Production processes with lead-times and standard allowed minutes (SAM)

For most of the production processes the calculated time is roughly the same as the actual time it takes to produce except for the knitting process where the SAM minutes are almost double. This is due to the increased need for manually controlling the production process, somebody almost have to stand
next to the knitting machine the entire to make sure that what is produced has 100 per cent quality. The total value adding time in the production process is 126 minutes. With set up times and waiting times the production lead-time is 136.5 minutes. However, when the cost of the garment is calculated, the total time is calculated using the standard allowed minute. For example, in the knitting production step the allowance is 100 per cent due to downtime, set up time and problems that might occur with each new garment. Using SAM, the total lead-time equals 179.7 minutes. The production cost for a V-neck garment is 265 SEK. A equivalent standard garment would cost about 200 SEK to manufacture.

Discussion

The Knit on Demand concept would be described as collaborative customisation, where the customer changes both function (fit) and appearance of the garment (Gilmore and Pine, 1997). The concept is built on a platform design (Muffatto and Roveda, 2002) and it is not a free design in the sense that customer can change every aspect of the garment. Instead they are limited to a number of customisation options that are built into the modules, which have fixed interfaces so they can be attached with each other. From these modules an estimated number of 100 million combinations can be produced. The modules are pre-engineered and tested on before hand so that when there is an customer order we know that the knitting machine will produce a garment that has the required quality. There is also a fixed interface between the different modules so that the sleeves will always fit the body no matter how long or short they are. Modularity is also necessary because of the properties of knitwear, which is flexible and stretches in all directions. The flexible properties make it troublesome in the manufacturing processes, there might be a knot on the yarn that changes the tension of the yarn and suddenly the garment is knitted to loose or to tight.

The design of the garment and the connected knitting technology has supply chain implications. Figure 9 illustrates the differences between the two knitting technologies considered.

![Figure 9. Different CODP depending on knitting technology](image-url)
The upper flow illustrates cut and sew technology. It has the benefit that panels can be knitted on speculation and cut on order, which reduces the need for available knitting capacity after the customer order decoupling point (CODP). The lower flow illustrates fully fashion technology, which has the benefit that the seams are lighter and that there is now waste of material since the pieces are shape knitted. In the knit on demand concept a combination of fully fashion and cut and sew has been used. The body and sleeves were knitted using fully fashion technology and then the neck hole was cut into the right shape and then a collar was attached.

As Sami and Yasser (2009) wrote, it is difficult to measure magnitude of customisation since there are so many parameters that have to be included. For example, what is the maximum number of combinations? If every loop of a knitted garment could be mass customised to fit the individual preferences of each customer, which would allow for a virtually infinite number of combinations. In this case roughly 100 million combinations are possible, out of only one base module. If another module would be added the number of combinations would increase to 200 million combinations. However, that does not say very much about the efficiency of the system and about customer satisfaction. Cost does not double because there are twice as many combinations, nor does lead-times increase. The added complexity of another 100 million combinations would of course require increased control in the supply chain processes but it does not say very much about the performance of the supply chain.

Since mass customised products are one-offs it is important that the quality is 100 per cent. This is reflected in the manufacturing cost, mainly in the knitting process that cost almost double compared to a mass produced garment. Alvan and Aydin (2009) also concludes that mass customisation systems have lower productivity compared to equivalent mass product systems.

Conclusion

Tseng and Du (1998) wrote that a successful product family architecture (PFA) is based on concurrent engineering, optimal commonality, configuration rules, product line taxonomy, and economic evaluation. Most of that is covered by platform design (Muffatto and Roveda, 2002). In this concept, one base module that build on one sleeve module and one body module is able to offer the customer roughly 100 million combinations. Even though that may seem a lot and perhaps almost a free design it is not. The customer is limited to a range of 12 colours, six models, contrasting colours, a few accessories and the customers can have the garment made to measure. In this case it is the fixed interfaces between the different modules that are help managing complexity. The platform-based design also helps to reduce variance in the knitting process. Tseng and Jiao (1996) claimed that the essence of mass customisation is to offer an individual product without the corresponding increase in price and lead-time. However, the cost of manufacturing a mass customised knitted garment is about 25 per cent more expensive than an equivalent standard
garment. This is mainly due to the extra control needed in the knitting process to make sure the garments have 100 per cent quality.

References


Paper II

Knit on demand – development and simulation of a production and shop model for customised knitted garments

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Development of computer technology and the Internet has made mass customisation of products more common in fashion design of today. Development in production of knitted garments has made it possible to make garments ready made, directly in the knitting machine. The objective of this article is to present a design, production and shop model for the “Knit on Demand” concept and to show how the complete garment knitting technology could be used for customised products. A business model with production equipment located in store is presented. Customers are involved in the design process and garments are customised to fulfil actual demand. A lead time simulation of design and production processes in the shop concept is presented. Simulation in the software tool AutoMod™ shows that the customer could have a self-designed garment in two to five hours.

Keywords: Knitting technology; mass customisation; fashion design; manufacturing technology; fashion logistics

Introduction

Technical developments over the past 20 years have resulted in great innovation in the production of knitted fashion products. It is now possible to make complete garments directly in a knitting machine without the need of post-knitting processes such as cutting and sewing (Choi and Powell 2005). As a result, the time from yarn to ready-made garment can be shortened considerably. Not only are post-knitting processes largely eliminated, but several non-value-added operations can be dropped as well. Christopher and Peck (1997) state that one dimension of time-based consumption is time to market, i.e. how long it takes a business to recognise a market opportunity, translate this into a product or service, and to bring it to market. Time to market may be divided into value-added and non-value added time. Value-added time is an interval when something of value is added to the product, as example in knitting, finishing or sewing a garment. Non-value added time, on the other hand, is a period of waiting between value-added processes. It is of great importance to keep time to market as short as possible if one is to fulfil actual customer demand (Christopher 2000). Mass customisation is when the client takes an active part in the design process and chooses certain product features. The term ‘mass customisation’ has emerged from the familiar term ‘mass production’, which means the production of large quantities of standardised products, often using assembly line techniques. The definition of mass customisation varies at present and we have not arrived at any distinct and precise explanation of the term. It is more a buzzword according to Piller (2004), than anything else. The term mass customisation was first launched by Stan Davis in 1987. He described it as when a large number of customers can be reached, as in mass marketing but simultaneously can be treated individually, as in the era of customised markets in pre-industrial economies (Davis 1987). Pine (1993) has developed this further and defined mass customisation as a concept that provides such a variety and individual customisation that almost everyone can find what they want at prices comparable to mass produced products. Tseng and Jiao (2001) defined mass customisation as technologies and systems that can deliver products that meet an individual customer’s needs with nearly the same efficiency as that of mass production. Mass customisation is a future direction for the fashion and apparel industry, but garment fit and colour selection has limited its use (Fralix 2001). Lee et al. (2002) defined apparel mass customisation as a technology-assisted process that allows the customer to modify a company’s product line, in order to fulfil individualised design tastes or fit requirements of the garments. This is also the intention of the design and production concept described in this article.

Knit on Demand is a business model with knitting machines and other production equipment located in the shop or nearby. With this model the customer

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takes an active part in the design process and the garment is customised to fulfil actual demand. The garment is designed by the customer in a multiple-choice design system with several options when it comes to styles, materials, sizes, attachments and colours. A concept is developed where the customer places an order and the manufacturing takes place after the point of sales. With this approach there will be nothing produced that is not sold and the sell-through factor (the percentage of the garment sold at full price) will be much higher than if you would use a concept where the garment is produced ahead of the point of sales (Mattila 1999).

The purpose of this article is to offer a plan for combining the complete-garment knitting technology with mass customisation. This is done by presenting a shop and production concept for mass customisation of flat knitted products, built on complete garment-knitting technology. A lead time simulation of design and production processes involved in the shop concept is presented. The method used is based on the Knit on Demand concept and processes, equipment and lead times for the different parts are described. In-data for the simulations was studied for both design and production processes. A model was developed and used in a computer simulation of the concept. The results show the performance of the different parts of the concept, such as knitting machine efficiency and the time it takes for the customer to get a self-designed garment (demand fulfilment time). This article shows that complete garment knitting technology can be used for mass customisation, according to what was outlined by Choi and Powell (2005). Customer fulfilment time can be between 3 and 5 h. A key issue in the mass customisation concept of knitted products is the multiple-choice design system. However, this must be studied more in the future.

Method and research questions

The objective of this research is to develop and describe the Knit on Demand concept and to develop a model for simulation of the concept. The aim is also to present the result of a computer simulation of the concept performance, in particular regarding customer demand fulfilment time, production time and efficiency of the knitting machines in the system. A system state variables model of the Knit on Demand concept is developed and a collection of variables is defined to describe the system. A computer simulation of the model is presented, and the result shows how the different parts of the Knit on Demand business concept performs when it comes to customer demand fulfilment lead times and efficiency of the knitting machines in the system.

The method used in the research is based on the Knit on Demand concept where the different parts are described and studied in detail with respect to processes, equipment and lead times. The research is based on a survey of literature and discussions with suppliers of knitting production equipment. Input data for the simulations was studied and tested on the equipment for both design and production processes. The results of these tests provided information about lead times for all processes involved in manufacturing of the product, which was then used as input in the computer simulation. A model with focus on customer demand was developed and used in a computer simulation of the concept. The following research questions are addressed in this article:

RQ:1 What is the customer demand fulfilment time for Design in Shop/self-designed products in the Knit on Demand concept?
RQ:2 What is the efficiency of the knitting machines in the system?
RQ:3 What is the performance in terms of produced products for the different parts of the Knit on Demand concept?

Production methods for flat knitted fashion garments

The flat knitting machine has a linear needle bed that makes it possible to produce flat knitted rectangular panels for products like cardigans, sweaters, skirts, scarves and other garments (Spencer 2001). Flat knitting machines traditionally produce knit panels with a fixed edge and a welt at the bottom of the panel, coarse structures, and then such patterns as rib, Milano rib, jacquard, stripes or cables across the panel. The production from yarn to ready-made garment can be done in several ways with this technology, depending on production methods and the type of machinery used by the company. The production from yarn to ready-made garment consists of several processes, as shown in Figure 1. It starts with the knitting process, where yarn-on-yarn cones are knitted to panels in the flat knitting machine. The panels are often steamed in the finishing process after knitting. In the cutting process the panels are cut to the

Figure 1. Production process of flat knitted garments.
right shape and size, according to design quality requirements. The panels are joined together into a garment in the sewing process. To achieve the correct quality, the garment is often passed through a finishing process, such as steaming or washing. The traditional manufacturing of coarse flat knitted garments consists of several time-consuming processes after knitting.

The manufacturing process of flat knitted garments can be divided into the four different production methods, as shown in Figure 2: cut & sew, fully fashioned, integral knitting and complete garment.

**Cut & sew**

Cut & sew is the conventional and most common method for producing flat knitted garments. Panels for front, back and sleeves are knitted in a rectangular form and then cut into shape in the cutting process. Next the panels are sewn together with separately knitted trimmings and pockets to complete the garment. Both cutting and sewing are post-knit processes that take place apart from the knitting machine. With cut & sew, up to 30% of the original fabric may wasted as cut-loss. The advantage of this type of production is that it can be done on all flat knitting machines, including old models without computer processing systems. The disadvantages are the labour intensive post-knitting processes such as cutting and sewing, which makes this production suitable in countries with low labour costs, such as Eastern Europe and China. Another disadvantage is material waste in the cutting process. A high degree of the knitted material is cut-loss when the right form of the panels is formed in the cutting machine.

**Fully fashioned**

Fully fashioned, or shaped knitting, is a method of production, where the front, back, and sleeve pieces are knitted in the right shape directly in the knitting machine. The cutting process is at a minimum or totally eliminated, but some post-knit cutting can still be necessary. Trimmings and pockets are knitted separately and sewn together with the rest of the knitted pieces to complete the garment. The benefit of this production method, compared with the cut & sew method is that cutting is eliminated or kept to a minimum, and that the material consumption is much lower due to lower cut-loss. Both material and labour costs are lower than the cut & sew production method.

**Integral knitting**

Integral knitting means that trimmings, pockets, buttonholes and other accessories are directly knitted in the fully fashioned produced panels. With this

<table>
<thead>
<tr>
<th>Cut &amp; Sew</th>
<th>Fully Fashion</th>
<th>Integral knitting</th>
<th>Complete garment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front panel</td>
<td>Back panel</td>
<td>Sleeve</td>
<td>Sleeve</td>
</tr>
<tr>
<td>Front panel</td>
<td>Back panel</td>
<td>Sleeve</td>
<td>Sleeve</td>
</tr>
<tr>
<td>Front panel</td>
<td>Back panel</td>
<td>Sleeve</td>
<td>Sleeve</td>
</tr>
<tr>
<td>No cutting and no sewing process</td>
<td>Complete garment</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Production methods for flat knitted fashion garments.
Complete garment

In complete garment production the entire garment is ready-made directly in the flat knitting machine. The different parts of the garment are knitted in the right shape and knitted together with the trimmings, pockets and other accessories. As shown in Figure 3, the advantages with this technique are many. There is no waste of material such as cut-loss in the cutting process and no expensive post-knit processes such as sewing or cutting. Depending on the style of the garment, some additional cutting and sewing of labels and trimmings may still be necessary. All yarn in the garment comes from the same yarn cones, which enables higher quality and reduces problems with yarn from different dye lots. Due to seamless technology, the garment could both fit perfectly and be comfortable to wear. This technology makes it possible to reduce processes in the manufacturing of the garment and produce ‘on-demand’ knitting, which can shorten production lead time considerably.

Complete garment – a technology for mass customisation

There are business concepts for fashion products, shoes and other items that combine modern manufacturing technologies with mass customisation. An example of this is the Finnish leftfoot company, where the customer’s feet are scanned in the shop, and this information is used to manufacture shoes with a perfect fit that are home delivered to the customer within 3 weeks (Sievänen and Peltonen 2006). Another example is the Internet-based German company Spreadshirt, which sells T-shirts with customers’ individually designed prints. The customer can choose between standard options of T-shirts, and then Spreadshirt produces the customer’s self-design on the garment with modern digital printing technology (Reichwald and Piller 2006). The knitting technology of today makes it possible to manufacture products of a wide variety of materials, models, structures and patterns using complete garment technology. The cost saving benefits with no material cut-loss and a minimum of post-knitting processes make this technology one of the future production methods for knitted garments (Choi and Powell 2005). This manufacturing technology with flat knitting machines producing complete garments has been on the market since 1995, where Shima Seiki in Japan and Stoll in Germany have been the two leading machine manufacturing companies of this technology (Hunter 2004). Details of the new knitting technology can be found in an article by Mowbray (2002). However the real benefits of this new production method are not limited to savings in material and labour in the manufacturing processes of the garments that are produced. To be successful and reap all possible benefits, it is necessary to adapt the production system and the whole supply chain from producer to customer to a new concept. It is not enough to just buy a new knitting machine and install it in the same production and business system as before. The manufacturing technology of complete garments makes rapid design changes according to customers’ requirements possible through computerised manufacturing and fashion design systems. In combination with mass customisation, complete garment technology opens up new business opportunities with the advantages of shorter order fulfilment leadtimes, high customer service levels and strategies of postponement. In certain markets complete garment manufacturing technology could be useful for mass customisation based on the use of technology and management methods to offer product variety and customisation by flexibility and quick response. Computer-aided design (CAD) and manufacturing technology is one key factor in mass customisation (Onal 2003). There is not much information found in literature about customisation of flat knitted products but there is one example of customisation of flat knitted products in Japan. In 1995 Wajima Kohsan Ltd. opened Factory Boutique Shima in Wakayama, a shop for on-demand production of customised knitted garments. In 2008 the company opened its second shop in Japan. Knitting technology, combined with modern computer technology and a new business system, offers a concept wherein it is possible to customise each garment and make ‘batch-one’ manufacturing. In the concepts of logistics, the philosophy of quick response is an important, established factor in the fashion and apparel industry, as shown by Lowson et al. (1999). Complete garment technology, combined with a
demand-driven logistics system, could be a platform for a new concept in the business of knitted garments.

Knit on demand
Knit on demand – the concept

Knit on Demand is a business concept based on combining the manufacturing technology of complete garment production and mass customisation. It is a business concept that gives the customer the possibility of designing and customising a flat knitted garment in the shop. This garment will then be manufactured in the work room of the shop directly after the point of sales. The Knit on Demand concept makes it crucial to keep personnel and equipment occupied in order to achieve high cost efficiency from the system. It is of highest importance that the Knit on Demand shop gets the right location and that the right marketing of the concept is performed. For these two issues there must be experts in marketing involved in launching this concept. One of the disadvantages of the system is that it is very likely that customers will not come to the shop in equal numbers and regular intervals; there will be too few or too many customers in the shop any given time. Few customers will mean that personnel and equipment are not occupied and only cost money. Too many customers at the same time will cause queues, resulting in delay of deliveries. To overcome these problems, the business model must take such scenarios into consideration. With this as a background, the Knit on Demand concept consists of the four logistics parts shown in Figure 4: Design in Shop, Designers’ Place, Ordinary Production and the Knit Production Section.

Design in Shop is the part of the concept where customers make their design, and the garment is manufactured after the point of sale. Here the customer will have the opportunity of looking at fashion magazines, swatches of knitting structures, colour charts and garment samples for items that can be produced in the shop. Also, garments in various sizes can be tried on to match a perfect fit. If a person wants to design his/her garment they will be guided by a shop assistant skilled in design to create a customised, personally designed garment. The customisation of the garment takes place in a multiple-choice design system, where options for the design alternatives may be chosen from alternative styles, materials, colours, structures and sizes. There is also the option of having embroidery on the garment. The customer will be involved in the design process, but this will not be a free fashion design in the sense that the customer can create a new product without limitations. It is a design with options presented in the multiple-choice system. When this multiple-choice design is made, a printout is done; the customer can see the result of the work and also gets the possibility to dress virtually and have a photograph taken in the self-designed garment. After this procedure the customer can decide whether or not to purchase the garment. If the answer is yes, this will generate an order to the production unit of the shop.

Designers’ Place functions as an ordinary shop with garments that are pre-produced and available to buy. The garments are designed with complete garment technology, where one purpose is to give examples of what can be made in this design. A garment purchased in this section will be replaced as soon as possible by a garment from the production section. An order goes to the knitting production section that will manufacture the garment as soon as possible and deliver it to the Designers’ Place Section. This will keep this section occupied when there are no orders from customers’ self-designed products in the Design in Shop section.

Ordinary Production will be the normal mode of production for a knitting company. Therefore, the Knit on Demand concept must be developed together with a knitting production company that has its own products and customers that enable continuous activity in the production section. With these three scenarios of production there will be a higher degree of efficiency in the system. Moreover, when there are no customers for Design in Shop the other parts could maintain the production in the Knit Production Section. The layout of the Knit on Demand concept is shown in Figure 5. A space of approximately 100–120 m² will be required, and it will be divided into three sections:

1. Design in Shop
2. Knit Production Section
3. Designers’ Place

In the Knit Production Section the garment will be manufactured from yarn to complete garment, ready for the customer to wear. Manufacturing consists of several processes with the number depending on material composition, style, attachments, etc. If no
customers want to self-design garments or buy any from the Designers’ Place, the Knit Production Section can revert to manufacturing the knitting company’s ordinary production.

**Design and customisation by the customer**

Kaplan and Haenlein (2006) describe mass customisation as a strategy that creates value by some form of interaction between the company and the customer at the fabrication/assembly stage. One approach to customisation stated by Lampel and Mintzberg (1996) is tailored customisation. This is when the company presents a product prototype to a potential buyer and then adapts or tailors it to the customer’s demand. Also, Gilmore and Pine (1997) describe this collaborative approach with a dialogue with individual customers to help them identify their needs and design or customise the product. In the Knit on Demand concept we adapt this thinking about collaborative design between company and customer. The Design in Shop concept of Knit on Demand allows the customer to design his/her sweater and also customise it according to his/her requirements and needs. The path from the customer entering the shop until his/her personally designed garment is manufactured, sold and delivered is shown in the following steps:

1. Entering the store
2. Browsing in the store
3. Design in the multiple-choice design system
4. Photography of the customer virtually dressed in the garment
5. Point of sales
6. Production
7. Paying at the counter
8. Delivery

The idea is that the customer comes into the shop and looks at sample garments, yarn and swatches on display. After deciding on a self-designed garment, the customer is guided through the design process by a design technician from the shop staff. This process is a multiple-choice system, in which the customer gets options in several stages from the beginning to the end of the design process. The multiple-choice system presents options and at the end of the process a custom designed garment is shown to the customer. The design options in the multiple-choice system will be pre-programmed into the knit CAD computer in a modular system, where the customer’s preferences can be combined together to make up a garment that can then be transferred to a knit program so the machine can knit the actual product. A photo printout with the customer virtually dressed in the newly-designed garment will thus be available. It is of highest importance that the fashion input is up to date and that new design and styles are developed continuously. This must be done by a fashion designer experienced in knitting design. In the beginning we have limited the available materials to cotton and wool in order to be able to fulfil our high quality requirements. When this works, it is of course our intention to increase the design variety in the future. For the finishing process we have a steam table, washing machine and tumble dryer. This finishing equipment combined with the right knowledge and experience will produce the products that the customers demand. The combination of fibre material, structure and the finishing process will be a key factor in the Knit on Demand concept.

**Manufacturing the product**

Manufacturing the products takes place in the workroom of the shop, in sight of the customer. This concept makes customers part of the whole process, from idea and design to the manufacturing of the product. After the design process and point of sales, the manufacturing of the product starts as quickly as
possible. Depending on how many customer-designed products are ahead in the system, there may be a queue for the production facilities. Process time for design is estimated to 30 min. Manufacturing the garment consists of knitting, washing, tumble-drying, steaming and some additional sewing and embroidery. Preparation or set-up time for each process is estimated to be between 1 and 5 min, depending on the type of preparation needed. The estimated time required for each process is based on information from machine manufacturers and tests made at the Swedish School of Textiles in Borås, Sweden. As shown in Table 1, the total theoretical time for manufacturing processes for a customer designed garment in this case will be in the range of 166–188 min (Nilsson and Olofsson 2006).

People working in knit on demand

The personnel working in the Knit on Demand shop will be very important for the performance of the business. In the production unit of the shop there will be one or two persons working with the manufacturing of the garments. These persons must be well-experienced knitting technicians with good knowledge of programming and knit manufacturing of flat knitted garments. They must also have substantial experience in different kinds of finishing processes of flat knitted products to be able to manufacture sweaters of high quality. When it comes to the shop assistant, this person is one of the key factors in the co-design interaction process for the customer. This person must be skilled in fashion design. A good knowledge of pattern construction and sewing to be able to help the customer to the right personal fit measurements of the garment is also required. This type of business, where customisation of the product is done in the shop, opens up new possibilities for the personnel working in the fashion retailing business. The people working in this type of business concept need to have much more skills in design, sewing and apparel manufacturing than is normal for personnel in a fashion retailing shop. This also requires new types of education in the future. Education with a mix of traditional fashion apparel skills, combined with knowledge in retailing of fashion products.

The simulation model

Simulation modelling method

A model can be explained as an artificial representation of an actual system. A model should also contain details, but no more details than necessary to provide the desired results. The simulation method used in this article is the process-interaction method with the basic function to emulate the flow of an object through the system. The object moves through the system until it is delayed, enters an activity, or has been completed by the system. When the object is stopped, time is advanced to the next movement. This flow describes in sequence all processes, waiting times, or other states the object can attain in the system. Each process and event in the model is simulated (Banks 2000). The simulation model used in this article is of the discrete-event simulation type. This means that the model represents the components of a system and their interactions. Discrete-event models are time-based with the results a product of the interactions of system components. The model for the Knit on Demand concept consists of the different components in the system and the values for these components. The Knit on Demand simulation model used in the simulation runs consists of four parts, as illustrated in Figure 4: Design in Shop, Designers’ Place, Ordinary Production and the Knit Production Section.

The simulations were performed with two knitting machines in the knit production section. Each simulation represented 200 h and was repeated 15 times. All production lead times for the final simulation are displayed in Table 1. The simulation begins at the point of sales (when the customer orders the product) and concludes when the customer receives the finished garment and has paid for it. The aim of the model is to give priority to the knitting machines in order to maintain the highest efficiency as possible of the

Table 1. Design in shop, preparation and process lead times.

<table>
<thead>
<tr>
<th>Process</th>
<th>Knitting</th>
<th>Washing</th>
<th>Drying</th>
<th>Steam</th>
<th>Sewing</th>
<th>Embroidery</th>
<th>Total process time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2.5</td>
<td>11.5</td>
</tr>
<tr>
<td>Process time</td>
<td>55*</td>
<td>36</td>
<td>14</td>
<td>30</td>
<td>4</td>
<td>5</td>
<td>176</td>
</tr>
<tr>
<td>Total lead time</td>
<td>60</td>
<td>37</td>
<td>15</td>
<td>31</td>
<td>5</td>
<td>6</td>
<td>187.5</td>
</tr>
</tbody>
</table>

*The knitting time is triangularly distributed between 35 and 70 minutes with a mode (the most likely value) of 55 minutes. This is due to the different knitting times for different models, thread breaks, and errors that occur.
machines. The simulation is made in the AutoMod™ simulation system; a system for building models and simulating detailed design, materials handling and manufacturing processes. A model and simulation of the Knit on demand concept was developed in AutoMod™ Version 11.2.

**In-data for the simulation**

Production lead time data is based on information from machine equipment companies and our own trials conducted at the Swedish School of Textiles. Data of customers entering store is based on a study at the fashion shop where Knit on Demand shop is to be situated. Each simulation lasts for a period of 200 h; the shop is open to the public for 9 h a day. These 200 h correspond to approximately 1 month of the shop’s open hours. An exponential distribution is used to model random arrivals of customers into the shop with the expected value of 6 min. This means that a customer is assumed to enter every sixth minute, but as the exponential distribution is without memory, the probability that a customer enters the shop within the next minute will not rise, as times goes beyond the expected value. The probability for the customer to start a self-designed sweater is estimated to 10%; it is estimated that 50% of the customers who start to work with the ‘multiple-choice design system’ buy a product. Approximately 50% of those customers will choose to add embroidery to the garment. The probability that a customer will buy a Designers’ Place sweater is estimated at 15%. Post-production cash register time is estimated to be 90 s. In the model, two persons are engaged in the Knit on Demand system. One person works in the shop part of the system, guiding customers in the choice of product design, selling garments in Designers’ Place, and managing the cash receipts. The other person operates the Knit Production Section of the system where the garments are manufactured. The simulation model is built giving precedence to the knitting machines, as the knitting machines in the production section represent the most expensive investment of equipment in the concept and thereby given the highest priority in the system. Thus, if an operator works with another process, he/she suspends this process and begins operating the knitting machine. The materials used for the products in the simulation are wool and cotton. The main difference between wool and cotton in production is that the washing time is longer for cotton garments, as wool garments are much more sensitive to mechanical friction due to felting of the wool fibre. The probability for a purchase of a woollen or cotton garment is equal for all products produced.

**Results of the simulation**

To illustrate the results from the simulation, charts were made using the output data. The figures below show the summarised result of the simulation. As an example of one of the fifteen simulations shown in Figure 6, demand fulfilment time for cotton and woollen garments varies from 130 to almost 300 min. Most garment samples are in the range of 160–220 min. The total result shows that demand fulfilment time for the customer varies from 120 to 301 min. The demand fulfilment time for cotton products averages 206 min and 191 min for woollen products (Figure 7). This means that the time elapsed from the point of sales to the final point where the customer pays for the finished garment on average is 206 or 191 min, respectively. At a minimum, a customer could have a woollen garment in 120 min or a cotton garment in 137 min (Figure 7). The difference in time for wool and cotton garments depends on the fact that there is a time difference in

![Figure 6. Demand fulfilment time for one 200-h cycle simulation for self-designed garments.](image-url)
the washing process. Figure 8 shows the number of garments produced and sold in the different parts of the Knit on Demand system. In the Design in Shop part where customers choose options for a self-designed garment, a maximum of 113 and minimum of 75 (average 95) are sold. The Designers’ Place maximum is 282 and minimum is 244, (average 263 garments) in the demand fulfilment process. The result of the simulations shows that the efficiency of the knitting machines varies between a minimum of 79.1% and a maximum of 90% (average 86%) visualised in Figure 9. The total number of garments produced on the knitting machines during the simulations ranged from 341–386 and the average number of garments produced in all 15 simulations was 367.

Figure 7. Demand fulfilment time for self-designed garments produced during 15 simulations. Available in colour online.

Figure 8. Total number of products, produced and sold in Design in Shop in 15 simulations. Available in colour online.

Figure 9. Efficiency of knitting machines and total number of garments produced in 15 simulations. Available in colour online.

Conclusion

In this article the benefits of complete garment technology when combined with mass customisation are described and implemented in a business and production system of the Knit on Demand concept. An overall aim of research and research questions has been formulated and a business model has been developed. This model has been used for an AutoMod™ computer simulation of the shop concept.

Research question 1 was: What is the customer demand fulfilment time for a self-designed product in the Knit on Demand concept? The result of the simulation shows that the demand fulfilment time is between 120 and 301 min. The customer can have a garment in the range of 2–5 h. A delivery within 2 h requires a garment with a minimum knitting production time and without embroidery. This also means that there must be no waiting time and no queues in the system.

Research question 2 was: What is the efficiency of the knitting machines in the system? The result of the simulation shows that the efficiency of the knitting machines is 79.1–90% (average 86%), which is a relatively high degree of utilisation. To improve the efficiency of the knitting machines, their set-up times must be minimised.

Research question 3 was: What is the performance in terms of manufactured products for the different parts of the Knit on Demand concept? The performance in produced garments in the model and simulation set-up resulted in an average of 367
produced garments in the system. On an average, 95 customer-designed garments were sold in the Design in Shop part of the system.

The research objective of our research was to develop and describe the Knit on Demand concept and to develop a model for simulation. This has been carried out, and input data for the simulation in AutoModTM has been identified. The results of simulations can be further improved by shortening the process lead times even more. The pre-study of process data shows that the washing process is a bottleneck in the production system. In the washing process the water must be heated in the washing machine before the actual washing starts, and this takes time. A solution would be to pre-heat the water so that washing can start as soon as the garment is put into the machine. This could considerably shorten the time for washing. It has been shown that using the complete garment technology and its production system has made it possible to greatly cut lead time from customer demand to customer demand fulfilment.

We have endeavoured to show that a high fashion, customised garment may be designed, sold, and produced in 2–5 h. According to Christopher (2000), it is of great interest that time to market is kept as short as possible to be able to fulfil actual customer demand. Our findings show that complete garment knitting technology, in combination with mass customisation, fulfils this interest. This result supports the conclusions of Choi and Powell (2005) that complete garment technology can be considered for mass customisation of knitted garments. The Knit on Demand concept shows an alternative way for European knit fashion producers to shift from mass production to mass customisation, instead of relocating the production to low cost countries. This work does not consider financial aspects such as price of the products or profitability of the concept in account; it only analyses the design and production process of the concept. It proves that there often are problems with demand fulfilment time in the fashion industry and suggests how this might be solved in the range of flat knitted fashion products. Future work will be to study this business model further and to develop the different parts of the system. The multiple-choice design system must be developed and customised; manufacturing processes have to be optimised. How are dissatisfied customers to be handled? Could the products be delivered to the customer directly? The answer is yes if there is no queue in the system. If there are too many customers wanting to do a self-designed product during the same period of time there is a problem. Research shows that actual customer demands ideally should be fulfilled on location. If this is impossible, delivery by parcel post is the second best solution. This is done in other type of sales like mail-order or Internet sales. How this will affect the customer’s attitude towards the Knit on Demand concept must however be further studied. One of the key factors in a concept like this is the personnel that will be working with the customers in the shop and future studies will have to be made into which requirements they will have to meet in the areas of design and fashion apparel. One idea is to do this in a research project involving fashion apparel students and a fashion retailing company. The financial aspects of the concept also need to be studied. As this article points out, complete garment technology opens up new perspectives on customisation of the fashion industry’s flat knitted products.

Note

1. Portions of this work were presented at ITMC-Intelligent Textiles & Mass Customization International Conference, November 15–17, 2007, Casablanca, Morocco.

References


Paper III

Evaluation of risks in a supply chain for customised knitwear

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ABSTRACT

Purpose of this paper

It is generally accepted that short lead-times, postponement of processes and production close to the market decrease risk in supply chains. Knit-on-demand is a research project at the Swedish School of Textiles in collaboration with a knitwear manufacturer and a fashion retailer. In the project a business concept for mass customised knitwear has been developed and tested.

This paper presents an evaluation of a risk analysis performed in 2007 on the Knit on Demand project. The evaluation in 2011 is made to conclude whether risks decreased with the mass customisation concept and if the expected results were the same as the outcome.

Methodology

The case study method is used and sources of evidence are interviews, documents, and value stream mapping. The data from the case studies are then converged in a “What-if” analysis.

Findings

The evaluation revealed how the risk level changes in a supply chain when introducing a mass customisation concept for fashion garments.

Practical implications

The concept was tested in its business environment for one year and four months. The tools developed for managing supply chain complexity and -risk in the Knit on Demand project are applicable to conventional knitwear production as well.

Keywords: Supply chain risk management, Mass customisation, Fashion logistics, Knitwear, risk evaluation
1. INTRODUCTION

Knit-on-demand is a research project at the Swedish School of Textiles. The objective of the project is to demonstrate a production method for knitwear that may strongly influence the ability of the fashion industry to meet new demands for agility in customer relations. The project is a collaboration between the Swedish School of Textiles; a knitwear manufacturer - Ivanhoe AB and a retailer of customised fashion - SOMconcept AB. Both the manufacturer and the retailer are located in Sweden. The Knit on Demand concept has its starting point in mass customisation; a business concept that was anticipated in the seventies by Toffler (1970) and later defined by Pine (1993). The essence of mass customisation is to transfer the configuration process to the customer and then produce it at near mass production efficiency.

The starting point of the paper is an analysis of supply chain risks in the Knit on Demand project. The purpose of the risk analysis was to "...assess and manage risks in a Swedish knitting supply chain from a demand-chain perspective. It was performed on the knitwear manufacturer Ivanhoe AB using the “What if?” risk analysis tool. A What if?-analysis is a speculative tool often used when developing processes. When performing a What if?-analysis a number of questions are formed on; What if…happens? To answer the questions a multi disciplinary group is gathered (Harms-Ringdahl, 2001). In the Knit on Demand risk analysis in total 21 practitioners and researchers with different backgrounds were involved.

There are always arguments about what is risk and what is not. Kaplan (1997) wrote that “...maybe it's better not to define risk. Let each author define it in his own way, only please each should explain clearly what it is.”

Harland et.al (2003) wrote that risks usually incorporate some kind of loss. Either financial loss, performance loss, physical loss, psychological loss, social loss or time loss. A loss is generally quantified to damages or prison sentences. It makes sense that the word risk is used in a negative sense even if the International Standard Organisation has defined it as: effect of uncertainty on objectives (Purdy, 2010). Here is the definition of risk used in this paper, for convenience reasons it is the same as the one that was used in Knit-on-demand project:

The probability of the occurrence of a negative event, times the consequences of that event.

As framework for the analysis and for identifying sources of supply chain risk a model suggested (Figure 1.1) by several authors such as Jüttner (2005), Christopher and Peck (2004), and Tang (2006) was used. The identified risks were evaluated according to probabilities of occurrence and consequences.
The evaluation of risks in the Knit on Demand concept consist of two parts, the first part was performed in 2007 and the investigation revealed the most evident risks in the supply chain under study as well as in the proposed future supply chain. The second part was performed in 2011 and is an evaluation of the first risk analysis using the knowledge and the experiences from the project to verify or falsify the earlier results. These are the conclusions from 2007 (Andersson and Ottosson, 2007):

- The proposed transformation of a supply driven business strategy from a to a demand driven seemed to eliminate several of the risks and reduce others. Obviously, new risks were identified in the proposed state, which needed to be managed in the further development of the concept. Through a proactive approach, the risks can be managed, which will contribute to a higher grade of quality assurance.

- By producing closely to the market, problems in meeting volatility in demand, communication disturbances and overstocking can be reduced significantly.

- There are however risks arising with the “Knit on Demand” concept, due to the in-shop and on-time delivery announcement which increases customer expectations. This makes it extremely important to develop a strategy for assuring customer service.

This paper presents an evaluation of a risk analysis performed in 2007 on the Knit on Demand project. The evaluation in 2011 is made to conclude whether risks decreased with the mass customisation concept and if the expected results were the same as the outcome. This leads to the research question:

*Does the implementation of a mass customisation concept affect risk in a fashion supply chain?*

## 2. THEORETICAL FRAMEWORK

### 2.1. Mass customisation

Mass customisation as a concept was defined by Pine (1993). The idea was to produce unique products to each individual customer with close to mass production efficiency. The essence of mass customisation is that the customer designs, or configures a product, which is later produced by a manufacturing company. As a tool for decreasing risks in supply chain the concept of mass customisation has several benefits, the most obvious ones being that nothing is produced until there is a customer order, which means zero risk in ready-made stock. Compared to the fashion business in general where the forecast error is as much as ± 40 per cent 26 weeks prior to the season inventory risk could be significantly reduced. Other benefits are very low return rates, among the Swedish mass customizers of garments it is around one per cent (Larsson, 2009). Generally the customer designs a garment by choosing between models, colours and sizes. Drawbacks of mass customised products are that the customer has to design their garments themselves which increases the risk of mass confusion (Piller et al., 2005) due to the plethora of choices and leave the store without any purchased item (Huffman and Kahn, 1998). However, both Boyd and Bahn (Boyd and Bahn, 2009, Furnham and Ribchester, 1995) and Furnham and Ribchester (1995) writes that choice is good as long as it
is presented well. The order fulfilment lead-time is another obstacle to a purchase. Since the products are made to order there will always be a waiting time and it is not certain that the customers are used to such a set up.

2.2. Risk management

All risks cannot be avoided completely so it is important to plan for those situations where there is a potential risk. Mitigation means to reduce the severity, seriousness or painfulness of an event. Manuj and Mentzer (2008) puts risk mitigation in a pro-active sense. They suggest a number of strategies and mitigation plans to be used prophylactic to reduce the consequences of a disruptive event.

- Avoidance – used when a risk is considered unacceptable. Companies pull out of a market that is too risky or only compete in low-risk markets. One example is fashion mail-order companies that hinder the customers from buying more than one size and in that way reduces the risk of returns and ironically the chance of a purchase.

- Postponement – delaying the commitment of resources and material in order to maintain flexibility in production and capital. Postponement includes pricing, labelling, manufacturing and assembly etc. The ultimate goal is to postpone as many order-fulfilment activities until there is an actual customer order. A pure form of postponement is mass customisation where nothing is produced until there is a customer order (Feitzinger and Lee, 1996).

- Speculation – decisions are made on anticipated customer demand. The opposite to postponement. Concept driven fashion brands or brands with low visibility in their supply chain usually use this strategy.

- Hedging – by having a globally dispersed portfolio of suppliers, customers and facilities, a local single, disruptive event is less likely to affect on the whole supply chain.

- Control – by vertically integrating business processes gain control of its supply chain but it also less flexibility. Zara is well known for their vertically integrated business model that gives them control of their supply chain (Ghemawat, 2003).

- Transferring/Sharing risk – this can be achieved through outsourcing business processes to other organisations or by sharing profits and losses.

- Security – movement of nuclear, chemical and biological elements needs a high level of security that is able to identify and focus on suspicious elements.

None of these strategies and plans is used on their own but rather in combination with each other. Postponement is for example widely used in fashion supply chains but not until after the decoupling point (Cerruti and Harrison, 2006). Before the decoupling point the speculative risk mitigation strategy is used. The most popular and very often referred to example is Benetton that produces raw white garments and dyes them closer to the customer order point where demand is more certain (Dapiran, 1992). One closely related example to Benetton is the Quick Response movement that started in the U.S. apparel industry in the end of the 1980ies (Christopher and Towill, 2002). It is another example of risk mitigation even though it does not explicitly focus on risk. The Swedish telecommunication company Ericsson should perhaps have included hedging in their risk mitigation strategy portfolio prior to the 18th of March 2000 when a small fire in a small production cell at a supplier in
 Albuquerque, New Mexico stopped production of radio chips for three weeks ending up costing Ericsson $400 million (Norman and Jansson, 2003).

2.3. Supply chain risk management

In order to manage risks in a supply chain one have to know what the supply chain risk management is, Mentzer et.al. (2001) defines a supply chain as:

“A set of three or more entities (organisations or individuals) directly involved in the upstream and downstream flows of product, services, finances, and/or information from a source to a customer”.

Supply chain management would thus be the management of these activities and consequently supply chain risk management is (Tang, 2006):

“The management of supply chain risks through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity”

Risk sources linked to the relationships in the supply chain such risk sources can be either internal or external. Those risk sources become more important as the complexity of the supply chain increases (Jüttner, 2005). Jüttner (2005) also suggests a structure for supply chain risk management (SCRM). It consists of three layers of abstraction: Philosophy, principles and processes.

- A SCRM risk philosophy that builds on two pillars. The first one being openness and willingness to accept risks as common in the supply chain, and to share information about risks. The second one is the willingness to share those risks. Some companies are more willing to share risks and information about risks in the supply chain.

- Principles that if a company is to have any use for SCRM, risk have to be included in their supply chain strategy. It does however mean trade-offs between risk performance and the over-all business performance.

- Last the processes, which is the lowest level of the three layers. This refers to the work activities, the tools, the techniques and the coordination of these across time and place.

2.4. Robust and resilient systems.

Two concepts are often heard in supply chain risk management, resilient and robust processes. If a process is robust it is steady and can take hits well without changing its state. If it is resilient it has the ability to return to its original state or a new, more desirable state after being disturbed. A resilient supply chain seems to be preferred to a robust one (Christopher and Peck, 2004). Christopher and Peck (2004) writes that there are mainly four characteristics of supply chains that are obstacles for resilience. These are long lead times, single source of supply, poor visibility between the nodes and high risks in demand, process control and environment. Traditional fashion supply chains often showcase these characteristics, the result of it is usually poor sell through factor of only sixty per cent for up-front buying 26 weeks prior to season (Mattila et al., 2002, Christopher and Towill, 2002) and forecast errors of ±40 per cent (Christopher and Towill, 2002). Christopher and Peck (Christopher and Peck, 2004) concludes that out-sourcing, globalisations and the creation of complex networks of
interdependent organisations increases risks and that many organisations respond to this with efficiency improvements while they instead should have focused on flexibility and agility. Agility as described by Cerruti and Harrison (2006) has several similarities with mass customisation. The market sensitiveness and integrated processes are perhaps the most evident commonalities. Sharing data between the supplier and customer comes with the integration of processes. Since agility is a part of a resilient supply chain it may be suggested that a supply chain that has implemented a mass customisation concept could be described as more resilient.

3. **METHOD**

The risk analysis consists of two parts. In the first part, performed in 2006 the conventional supply chain was analysed and it was also suggested how the Knit on Demand concepts could reduce those risks. There is also a brief description of events in the project with mayor impact on the outcome of the project and thus on the result from the risk evaluation that was performed in 2011. Since the Knit-on-Demand project is a real-life concept that is tested in a business environment. For the study of such projects the case study method is suitable. Yin defines case study as (Yin, 2009):

“A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life, especially when the boundaries between the phenomenon and the context are not clearly evident.”

**3.1. The first risk analysis and the development of the project**

In the first risk analysis two states of the supply chain processes were analysed, first the existing supply chain and in comparison to that, the future Knit on Demand supply chain. A number of deep interviews was performed with the production manager at the knitting company and the "What-if" analysis was chosen as a tool for identifying risks. The risk analysis was performed using the “What-if” analysis, which is a speculative tool often used when developing processes. When performing a “What-if” analysis a number of questions are formed on; What if...happens? How a “What-if” analysis is deployed depends very much on the situation. It is important that the team answering the questions is skilled and multidisciplinary to cover all aspects of the analysed situation (Harms-Ringdahl, 2001).

In the first risk analysis there was only one company were exposed to business risks. There was another company involved, a third party logistics provider, which had more of a consultants function. When the first risk analysis was performed in 2006, the plan was still that there should be a complete garment-knitting machine in a “Shop in shop” concept store in Gällstad and the machine was dedicated for producing garments to the Knit on Demand project. Customers would come into the store and together with a design technician design their own unique garment. It was not decided how much freedom of design there would be but the idea was that some kind of multiple choice system should be used and one was also starting to be developed (Larsson and Peterson, 2007). However, the costs if investment in a complete-garment knitting machine and the development of a multiple-choice system was considered too high. The concept would also require precious retail space. It was not until 2008 that the concept started to take on its final shape. In the spring of 2008 SOMconcept started to become seriously involved in the project and with them a sales channel for the garments opened. Instead of producing and selling the garments in Gällstad it was now decided that the garments should be sold in Stockholm at SOMconcept and produced by Ivanhoe in Gällstad. Thus the risk analysis has expanded to figure 3.1.
Figure 3.1 Sources of risk in the Knit-on-demand supply chain, developed version of Christopher and Peck’s model (2004) for sources of supply chain risk.

At the same time it was decided that there is no need to make a expensive investment in a complete garment machine. It seemed like the customers did not know the difference between a fully-fashioned garment and a complete garment anyway, the models were typical 12 gauge fully fashion garments and Ivanhoe already had that type of machinery. Instead of a digital multiple-choice system a manual ditto was built and used in the store.

### 3.2. Evaluation of the first risk analysis

One challenge in the evaluation of the first risk analysis is the risk analysis it-self. It has to be as similar as possible to the first analysis. Since the concept has changed quite a bit with the addition of SOMconcept AB and the different type of knitting machinery, parts of the first risk analysis is not applicable anymore and other risks has developed. However, the point of the paper is to compare the future state that was proposed in the first risk analysis to the actual future state.

In order to make the results from the risk analysis reliable, *multiple source of evidence* and *data triangulation* approach has to be used. There are four types of triangulation; data-, investigator-, theory- and methodological triangulation. For this case study mainly data- and investigator triangulation is used. When pursuing triangulation of data there are conditions that have to be fulfilled. For true triangulation, *upper portion triangulation*, data from different surveys are compared and conclusions are drawn from that. For *lower portion triangulation* the conclusions from different surveys are compared (Yin, 2009). In this case study a mix between upper- and lower portion triangulation is used. The original members of the risk analysis group were not available for the full round of risk analysis sessions one more time. The previous one included in total 21 persons divided on three sessions. Therefore an alternative method was used that did not require the commitment of all these people. A panel consisting of one professor in risk management, one expert in textile supply chain management and one of the researchers who has developed the concept is assembled and the results of this evaluation is then verified with the production manager of Ivanhoe AB. Figure 3.2 explains how the data converges triangulation converges in the “What-if” analysis which is then verified.
The risk evaluation tool was the same as the risk analysis tool, i.e. a “What if? - analysis” were all the risks were placed according to their magnitude in a probability-consequence diagram (scale: 1-10). Each of the risks got a risk level that determined their effect on the supply chain. The lowest risk level is 0, that means not applicable or no risk and the highest risk level is 100, which basically means total loss of sales.

4. RESULTS

In table 4.1 the top ten risks in each of the categories Conventional supply chain (Initial), Expected outcome of the project (Expected) and the Actual outcome of the project are listed. Only the ten highest ranked risks in each category are presented since they would have the largest impact on the supply chain. In the evaluation of the project, it turned out that some of the risks that were evident in the existing supply chain in 2007 or anticipated to have high impact in the Knit on Demand project had no impact at all or were considered not applicable. In the column Conventional supply chain refers to Ivanhoe AB’s supply chain before the Knit-on-demand project started in 2007. Expected outcome of the project refers to the expected results of the Knit-on-demand project developed according to the initial plan in 2007, and Actual outcome of the projects refers is the actual results of the project four years later in 2011. Since Ivanhoe did not change their entire set up just for this particular project quite a few processes remains the same as before, thus the probabilities of an event and the consequences of such an event remains almost the same. However, the risk analysis presents the risks in the Knit on Demand supply chain. None of the risks were had high enough consequences to put the company in bankruptcy so risk level 100 is equivalent to total loss of sales, exactly how much is difficult to measure since a potential customer who does not purchase seldom reveal themselves to the store staff.
Table 4.1 Result of the risk analysis and risk evaluation, top ten risks, RL = Risk level

<table>
<thead>
<tr>
<th>Conventional supply chain in 2007 (Initial)</th>
<th>Expected outcome of the project (Expected)</th>
<th>Initial RL</th>
<th>Actual outcome of the project</th>
<th>Initial RL</th>
<th>Expected RL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour shortage</td>
<td>The low cost profile of Gällstad does not fit the concept</td>
<td>80 N/A</td>
<td>Capacity shortage in general</td>
<td>100 N/A</td>
<td>N/A N/A</td>
</tr>
<tr>
<td>Market volatility</td>
<td>Wrong input from trend spotting</td>
<td>63 63</td>
<td>Customer does not understand the concept</td>
<td>90 0 42</td>
<td></td>
</tr>
<tr>
<td>Power fail in factory</td>
<td>Wrong inspiration trip</td>
<td>63 63</td>
<td>Misunderstandings due to poor communications</td>
<td>81 70 70</td>
<td></td>
</tr>
<tr>
<td>Inefficient warehouse</td>
<td>Designer off track</td>
<td>63 63</td>
<td>The low cost profile of Gällstad does not fit the concept</td>
<td>72 N/A 80</td>
<td></td>
</tr>
<tr>
<td>Over buying</td>
<td>Wrong pattern/design</td>
<td>54 54</td>
<td>Wrong product data</td>
<td>64 72 18</td>
<td></td>
</tr>
<tr>
<td>Wrong product data</td>
<td>Bad fit</td>
<td>54 54</td>
<td>Bad fit</td>
<td>63 54 54</td>
<td></td>
</tr>
<tr>
<td>SKU is missing</td>
<td>Waiting time in store</td>
<td>54 0</td>
<td>Inefficient warehouse</td>
<td>63 72 18</td>
<td></td>
</tr>
<tr>
<td>Capacity shortage due to machine break down</td>
<td>Bus load of customers</td>
<td>54 0</td>
<td>Poor sales performance at the retailer</td>
<td>60 36 0</td>
<td></td>
</tr>
<tr>
<td>Salesman does not like model</td>
<td>Customer does not understand the concept</td>
<td>42 0</td>
<td>Waiting time in store</td>
<td>54 54 0</td>
<td></td>
</tr>
<tr>
<td>Misunderstandings due to poor communications</td>
<td>Wrong labelling</td>
<td>40 40</td>
<td>Lead-time too long</td>
<td>50 0 0</td>
<td></td>
</tr>
</tbody>
</table>

Shortages was initially expected to have impact on the supply chain, labour shortage was ranked high as a risk but the risk with highest impact on the project was another type of shortage; capacity shortage. Since the capacity of the production plant was limited it was difficult to book capacity and hence difficult to give a lead-time promise. This was a problem since a lead-time of less then three weeks was guaranteed to the customer. The risk of the lead-time being too long is also in the top-ten list of the risk in the outcome column. Sometimes the lead-time promise was not met but that was nothing that customers were bothered about and no customer has refused a delivery because the lead-time was too long.

Communication related risks; “misunderstandings due to poor communications”, “the customer does not understand the concept” and “wrong product data” were also expected to
be reduced. However, since another partner was added the complexity of the supply chain increased and because of that communication related risks did not decrease. The risk of the customer not understanding the concept was also high but none of the customers said that they had difficulties to understand the concept, since the store staff explained the concept very well. It is not known how many customers that walked out of the store because they did not understand the concept so lost sales is not known. Inefficient warehouse is also connected to communication related risks, it happened that inventory levels of yarns were not communicated to the retailer and that products were sold that could not be produced. The effect of such an event was that the customer had to come back to the store and choose another colour.

The risk with the most obvious effect on the whole project was “The concept does not fit the low cost profile of Gällstad”. As it happened, the concept did not fit in Gällstad but very conveniently SOMconcept emerged as a partner and sold the garments in Stockholm instead.

Since the products are customised to fit each individual customer it is important that the fit is 100 per cent correct. In an event of a garment not being correct the result is not only a lost sale but also no chance of selling that garment to another customer since it will not fit any other customer.

“Poor performance of the retailer” is difficult to measure, however, a total of 37 sold products would certainly qualify as poor performance. If this has to do with “Waiting time in store” or that the customer did not understand the concept is difficult to measure. However, those customers that did buy a garment were very satisfied with the service in the store and fully understood the concept.

Most of the top ten risks in the outcome category are process related. Some risk levels have increased but the average risks in the supply chain has been reduced. This was also confirmed with the production manager at Ivanhoe AB.

Out of the top-ten risks in the expected column, four risks were considered applicable to the concept in its final state. The “low cost profile of Gällstad”, “customer does not understand the concept”, “waiting time in store” and “bad fit” all made it to the top ten in the outcome column. The other six were considered not applicable or reduced to zero in the projects final state. These were design related risks such as “wrong input from trend spotting” and “wrong pattern/design”. About half of the customers wished for more design options but that does not mean that the existing models were wrong. The risk that the customer does not understand the concept have high impact on a concept like Knit on Demand since it may lead to lost sales unless the store staff manages to explain the concept.

In Figure 4.1 the average risks in the different stages of the project are presented. The stages are initial risk before the Knit on Demand project started in 2007, the expected result in 2007 of the project and the actual outcome of the project in 2011.
Figure 4.1 Average risks in the Knit-on-demand supply chain

The initial risk level was 42.7, the expected outcome of the project was a risk level of 24.7. However, the consequences of an event were expected to be more severe than in the initial state. The actual outcome of the project is a risk level of 21.3 with both reduced probability of an event and reduced consequences in the case of an event. The expected probability of an event was equal to the actual probability of an event but the consequences was considered lower in the evaluation of the concept.

5. ANALYSIS

The initial risk analysis performed in 2007 revealed that the conventional supply chain had the same characteristics as any other fashion supply chain such as long lead times, communication problems and cultural issues. Thus it will also have the same issues as any other conventional fashion supply chain with low sell through factor and lost sales. Several risks were expected to decrease or disappear with the Knit on Demand project and the result shows that they did. Risks actually decreased more than initially expected.

Since Ivanhoe AB is a rather small company it has not developed an explicit risk strategy and hence it is difficult to divide the Knit-on-demand concepts risk management strategy in to Jüttner’s (2005) structure for supply chain risk management (philosophies, principles and processes). There are however similarities between Jüttner’s (2005) structure and the newly developed Knit-on-demand concept even if it is not explicitly said so. Since it is a supply chain for mass customised garments it is natural that the communication between the supplier and the retailer is more frequent. Hence, information about changes in customer demand will penetrate the supply chain faster. Similarities are mostly found on the process level since the concept for mass customised garments requires a higher level of commitment of production resources from the manufacturer and also far better and closer collaboration between the retailer and the supplier then in a supply chain for conventional garments. Usually in fashion
supply chains the manufacturer will produce the garments and ship them to the retailer and that is the end of the manufacturers commitment. In this concept, however, the manufacturer dedicates production capacity all through the season for manufacturing of sometimes sporadic and disturbing orders.

From the seven risk management tools that Manuj and Mentzer (2008) suggests two are obvious in the Knit-on-demand supply chain. Those are speculation and postponement (figure 5.1). Before the order point yarn is kept in the warehouse and when an order comes production of that particular garment starts. The manufacturer has pre-engineered modules for the sleeves and the body. Each model and size has a number, which is entered in the knitting machine and a garment is knitted. Postponement as a type of risk management is inherited with the concept of producing mass customised garments. Since they are mass customised no finished garments are produced on speculation and thus there is no risk in finished goods inventory.

![Figure 5.1 Risk mitigation strategies in the Knit-on-demand concept](image)

With the mass customisation concept design related risks would disappear or be reduced to zero since the customers design the garments themselves. About half of the customers did ask for more design options but that does not necessarily mean that the design was wrong, there simply were not enough options or the options were not presented in a way that made it clear to the customers what they could choose from. Concepts such as Knit on Demand does require a great deal of interest in fashion from the customer, a need such as very long arms compared to the rest of the body or some other kind of anatomical oddity that makes standard garments fit poorly. Such an interest or physiologic characteristic can not be expected from the general population, only up to ten percent of a population can be considered as “fashion innovators”, thus customers that are willing to spend more time and money on fashion than the average customer (Goldsmith et al., 1999).

The risk of customers not understanding the concept was considered to have high impact in the outcome stage of the concept. It may be so but it is very difficult to measure since customers who does not purchase anything, seldom make themselves noticed. Some of the customers experienced a little initial confusion but the presentation of the concept, both visually on the hangers and orally by the store staff helped to make the customer feel comfortable, thus reducing the risk for confusing the customer with choices in the way Furnham and Ribchester (1995) and Boyd and Bahn describes it (2009).

Lost sales is an inherited problem from conventional fashion supply chains and is by the industry considered a nuisance but also part of the business (Mattila et al., 2002). The method with the highest accuracy in measuring lost sales is to measure the service level, i.e. comparing the total number of stock keeping units in the beginning of the season with the number of stock keeping units at any time during the season. Still, the number of customers walking out of the store without finding their preference of choice is not visible. The Knit on Demand concept would, theoretically have a high service level and low lost-sales all through the season since the customer is offered a large amount choices, in the vicinity of one hundred million combinations. However, that remains to be proved.
The average expected probability of an event in the Knit on Demand supply chain is the same as the actual probability of an event but the consequences are considered lower in actual case. Compared to a traditional supply chain the risks are lower in a supply chain for mass customised garments. This is mainly due to the reductions in lead-time and the on-demand manufacturing concept. A large proportion of the business risk in a conventional supply chain for fashion products is associated with forecast errors (Mattila et al., 2002, Cerruti and Harrison, 2006) and those do not exist on finished product level in a supply chain for mass customised garments. If this supply chain is put in the perspective of resilience and agility it has removed four of the obstacles for resilience suggested by Christopher and Peck (2004), i.e. long lead times, poor visibility between the nodes and high risks in demand, process control and environment. Single source of supply, which is the fifth obstacle to resilience, is still there. The Knit on Demand supply chain is agile in the sense that it has many commonalities with how an agile supply chain is described, it very quickly answers to market changes, it has integrated processes and data about customer demand is shared between the different actors. Sharing data about the customer comes as a natural part of a mass customisation concept since it would not work unless the producer knows the end customer in detail. If agility as defined by Cerruti and Harrison (Cerruti and Harrison, 2006) is a proper term for describing a supply chain for mass customised garments and whether the supply chain can be considered as resilient (Christopher and Peck, 2004) has to be further analysed.

6. CONCLUSION

When comparing the risk analysis performed in 2007 to the expected results and the actual outcome of the project in 2011 the following conclusions can be drawn:

The average risk in the supply chain for mass customised knitted garments has decreased compared to the conventional supply chain and it is also lower compared to the expected result. The number one reason for the reduction in risk is the postponement strategy and that the customers are allowed to configure their own garments which supports earlier conclusions about postponement and risk (Feitzinger and Lee, 1996). The postponement strategy is an inherited part in the mass customisation concept and thus, other supply chains for mass customised garment can be expected to show the same characteristics. Shortage in capacity was not initially expected to have significant impact on the concept but in the evaluation it turned out to have very high impact. The reason is that the retailer wants to give the customer a definite delivery date but as long as the manufacturer cannot dedicate capacity it will be difficult. Risk also increased because of the added complexity of another partner in the supply chain. The risk of customer not understanding the concept is evident, it is a new concept and not all customers can be expected to be fashion innovators and have an interest or prior knowledge of designing garments. In the end, from a risk management perspective the Knit on Demand project had a more positive impact on the supply chain than initially expected.

REFERENCES


Paper IV

MASS CUSTOMISATION OF FLAT KNITTED FASHION PRODUCTS: SIMULATION OF THE CO-DESIGN PROCESS

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Abstract:

In 1995 the Japanese manufacturer Shima Seiki introduced the first complete garment knitting machine capable of producing a ready-made flat knitted article under the trade name WholeGarment. Recently, the company also developed a co-design software tool, Ordermade WholeGarment®, for the customisation of knitted fashion garments. Factory Boutique Shima, their retail shop for on-demand production of customised knitted garments, makes it possible for clients to modify a knitted garment according to personal taste in style, colour, pattern, and size. This study examines how such a process streamlines the interaction between customer and shop personnel, while expediting the programming of the knitting machine. In comparing the manual co-design process with the Ordermade WholeGarment® system, we use a computer simulation to analyze the efficiency and lead times of each concept. The case study method is employed with an inductive approach based on company visits and interviews.

Key words:

Knitting technology, mass customisation, co-design, complete garment, fashion design, simulation

Introduction

Technological developments over the past twenty years have opened up new possibilities for the production of knitted fashion products. A flat knitting machine can now manufacture complete garments, eliminating the need for such post-knitting processes as cutting and sewing [1]. The time from yarn to “ready-made garment” is thus shortened considerably, and several non-value-added operations are also rendered unnecessary.

Keeping “time to market” as short as possible is essential if one is to fulfil customer demand [2]. Similarly, mass customisation has been defined by Tseng and Jiao [3], as technologies and systems capable of delivering products that meet a customer's individual needs with nearly the same efficiency as mass production. One of the future directions of the fashion and garment industry appears to lie in mass customisation, but until recently fit and colour selections have limited its use [4]. Mass customisation of apparel from a customer’s perspective is considered by Lee et al. [5], as a technology-assisted process that allows the purchaser to modify a company’s product line in order to meet personal design taste or fit requirements. The co-design software tool described in this paper is intended to make such customisation possible.

The business model of Factory Boutique Shima actively is founded upon two systems that engage the customer in the design of a selected item. The result is not only a customised garment, but one manufactured in response to actual demand. Manual WholeGarment is an interaction process that has been in use since the first Factory Boutique Shima store opened, whereby design and customisation are done in dialog between the customer and shop personnel, while production equipment is located
nearby. In April 2008 a newly-developed “multiple choice design system” called Ordermade WholeGarment® was introduced. It offers the buyer a variety of options with regard to style, material, size, colour, and attachments. The Ordermade WholeGarment® system is the first in the industry that makes it possible to customise a garment and simultaneously transform the buyer’s preferences into knitting machine control data. This breakthrough both streamlines the human interaction in the customisation process and eliminates the tedious programming of the knitting machines. We examine the two systems through simulations that compare lead time, efficiency, and the impact they had on retail sales of complete knitted garments.

Methodology

The inductive method used in this study is based on a survey of literature, discussions with shop personnel, and company interviews. The field work was carried out at the firm of Shima Seiki, supplier of knitting production equipment and inventor of the prototype co-design system Ordermade WholeGarment®, and the fashion companies Factory Boutique Shima (Wajima Kohsan Ltd.) and SOM Concept. A research project entitled “Knit-on-Demand” at the Swedish School of Textiles, in collaboration with SOM Concept, was also a source of information [6]. The discussions, interviews, and a study of the co-design process in Japan represent the primary data collection. A literature survey comprised the secondary data. At the Japanese shop, one person acted as a customer and a garment was customised through the co-design process from beginning to end. Thus, information for the development of the simulation model was collected on-site in the real shop environment at Factory Boutique Shima. The customisation processes was studied in two formats: a) Manual WholeGarment co-design, b). Ordermade WholeGarment®. Both were evaluated and assembled as models for simulation in AutoMod™ in order to compare their performance. Qualitative interviews with factory representatives at Shima Seiki and retail staff at Factory Boutique Shima developed information about the two procedures. Verification of the input provided and the results of the simulations are compared with that provided by the three sources. Some limitations of this study may be the absence of actual customer behaviour in the data and the fact that it is based on a simulation, rather than observation in a real shop environment. The originality and value of the paper is that it compares manual with software assisted co-design and describes how the latter may be useful for retailing knitted garments in the fashion industry.

Discussion

Mass customisation, co-design, and the configuration process

Whether mass customisation can be successfully employed in the knitted fashion product industry remains a contested question. Pine [7], extended Davis’s definition of mass customisation to include variety and individualised options that would allow almost everyone to find what they wanted at prices comparable to mass-produced items. The term “mass customisation” has evolved from the familiar “mass production”, which continues to signify the manufacture of large quantities of standardised products by the use of assembly line techniques. Mass customisation, however, has been variously interpreted, and there is no precise definition of the term at present [8].

Some modern business concepts for fashion products, shoes, and other items have combined contemporary manufacturing technologies with mass customisation. An example of this is the Finnish left® foot company, where a customer’s feet are scanned by sales personnel. The information obtained is then used to manufacture perfect fitting shoes that are delivered to the customer’s home within three weeks [9]. Another example of mass customisation of fashion products is the Internet-based German company Spreadshirt that sells T-shirts whose graphics are individually designed by customers. Spreadshirt applies these unique designs to a selection of standard T-shirts using modern digital printing technology [10]. Other knitted fashion products can be customised in a similar manner.
Kaplan and Haenlein [11], define mass customisation as a strategy that creates value by some form of interaction between the company and the customer at the fabrication/assembly stage. An approach described by Lampel and Mintzberg [12], is tailored customisation. Here a company offers a product prototype to the customer and then adapts or tailors it to the buyer’s demand. Gilmore and Pine [13], term this a collaborative approach, that is, a dialogue with individual customers to help them identify their needs, and which the manufacturer either designs or customises the product accordingly. Bourke [14], Franke and Piller [15], and Weston [16], conclude that all known mass customisers use systems that are to some extent IT-based.

Mass customisation interaction platforms consist of three principal components: core configuration software that guides the user through the configuration process by means of questions that offer design options; a feedback tool for simulating the configuration so that the customer may visualize the product; and an analytical tool (not seen by the buyer) that translates the customer’s order into a list of material and information for production of the product, and then forwards the configuration to the manufacturing and other departments.

In the co-design process customers convey their preferences and these become the basis of the manufactured product [17]; [18]; [19]. When a customer selects options in a co-design system or “configurator”, they become a co-producer or “prosumer”, as Toffler explains [20]. In the literature, co-design frequently signifies the interaction of an individual consumer and a company during the configuration of a customised product [21]; [22]; [23]; [24]. Made-to-measure and consumer-driven design are both concepts that have been carried over into mass customisation from the terminology of mass production.

If a business is involved in the sale of mass customised products, the traditional order of development, production, and distribution needs to be reformulated from a linear to a concurrent or parallel process [25]; [26]. Closing the sale to the customer becomes one of the initial steps, rather than the final one. Streamlining the time-consuming manufacturing operations after the point of sale is the key to shortening delivery time.

Fiore, Lee, and Kunz [27], cite the two essential elements in mass customisation of apparel: co-design for a unique product, and body scanning for a better fit. In co-design the customer, generally with the aid of CAD technology or professional assistance, assembles an individualised product from a company’s offerings by choosing style, fabric, colour palette, pattern, and size. Body scanning may be employed to obtain or verify measurements if a perfect fit are required. The disadvantages of body scanning are three-fold: a) it requires an investment in specialized equipment, b) not all people wish to be scanned, and c) certain types of clothing require taking a customer’s measurements manually. The last-named procedure enables a dialogue between the purchaser and the sales person regarding the fit of a garment, an aspect often overlooked in promoting body scanning. On the negative side, taking measurements manually can be more time consuming and may raise issues of personal privacy.

One of the bottlenecks in the mass customisation concept for flat knitted products via complete garment technology has been the co-design process itself. Until now, it has involved manual interaction between the customer and the shop assistant throughout the customisation of the garment. A new system that could make the co-design process more efficient and profitable would be welcome.

**Factory Boutique Shima – A concept of manual co-design**

In 1995 the Japanese manufacturer Shima Seiki introduced the first knitting machine capable of producing a complete ready-made flat knitted garment. The company called their complete garment concept WholeGarment®. In the same year Wajima Kohsan Ltd. opened the first Factory Boutique Shima, a retail store specialising in on-demand production of customised knitted garments, in Wakayama, Japan. The company added a second Factory Boutique Shima in the same city in 2008. The two shops and their associated manufacturing unit employ about fifty people. Factory Boutique Shima is a business concept that combines knitting technology and mass customisation on the retail level. It enables a client to enter the showroom, design and customise a flat knitted garment, and then, have it manufactured promptly in a nearby production facility. The boutique provides customers the opportunity of examining fashion magazines, swatches of fabric, colour charts, and sample garment
for ideas in custom designing their own garment. A selection of garments in various sizes may also be tried on to assure a perfect fit. Figure 1 shows one of these storefront shops.

In the process of creating the customised item, the client’s measurements are taken by a shop assistant skilled in clothing design. The Factory Boutique Shima product line includes a variety of items made by the cut-and-sew, fully-fashioned, or complete garment manufacturing methods, with customisation options corresponding to each technology.

![Image](image_url)

**Figure 1.** Factory Boutique Shima’s flagship store, Wakayama, Japan

The sequence from the retail shop entrance to the point where the custom designed garment is delivered is shown in Table 1.

<table>
<thead>
<tr>
<th>The Factory Boutique Shima concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer enters store</td>
</tr>
<tr>
<td>Customer browses through catalogs and examines merchandise</td>
</tr>
<tr>
<td>Design and customisation of garment</td>
</tr>
<tr>
<td>Order placed and purchase prepayed</td>
</tr>
<tr>
<td>Manufacturing of customised item</td>
</tr>
<tr>
<td>Delivery of finished garment</td>
</tr>
</tbody>
</table>

After the customisation process has been completed (Table 2), a customer is still free to decide whether or not to purchase the garment. If an affirmative answer is given, an order is generated and sent to the shop’s production unit. This “manually customised” WholeGarment® product is then made without cutting or sewing, that is, the entire garment is created in one continuous operation on the knitting machine. Such a manufacturing process will results in a seamless product with a more perfect fit and drape than is possible to achieve in the case of conventionally sewn products.
Table 2. Steps in manual customisation

<table>
<thead>
<tr>
<th>Manual WholeGarment customization in Factory Boutique Shima</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item and style</td>
</tr>
<tr>
<td>Choice of material</td>
</tr>
<tr>
<td>Neck type</td>
</tr>
<tr>
<td>Sleeve length</td>
</tr>
<tr>
<td>Size (input of body measurements)</td>
</tr>
<tr>
<td>Choice of colour</td>
</tr>
<tr>
<td>Attachments</td>
</tr>
<tr>
<td>Customisation completed</td>
</tr>
</tbody>
</table>

When a garment has been finalized and pre-paid, it is manufactured as expeditiously as possible generally the same day. Yarn and other stock components such as buttons and labels are kept on hand. By reducing the number of processes involved, complete garment manufacturing makes it possible to produce a customised garment in less time than conventional methods. In Japan, delivery is generally made by parcel post, but if faster service is required (for example, on orders from abroad), express shipment is used. If shipping is expedited, a customised garment could reach a customer in 3 to 10 days after being ordered, depending on the production schedule and the destination.

**Factory Boutique Shima – A concept of co-design via configurator**

In contrast to the manual procedure just described, one of the Factory Boutique Shima stores has introduced a newly-developed co-design system to make the interaction between the customer and the company more efficient. This process, termed Ordermade WholeGarment®, enables the client to do more of the customisation independently, via a computerized system. The software tool developed by Shima Seiki is the result of many years of collaboration with Wajima Kohsan Ltd. and the experience gained in selling customised garments in their retail store, Factory Boutique Shima. The Ordermade WholeGarment® co-design system functions as an interface between the customer and the manufacturer. Options are presented in several steps, allowing a customer to choose materials, styles, colours, and such details as pockets and trims, as shown in Figure 2. This innovative software makes it possible to customise and design a fashion product with much less help from a shop assistant than before. The Ordermade WholeGarment® procedure has been used in one of the Factory Boutique Shima shops in Wakayama since 2008. The computer-assisted customer’s personally designed garment is co-designed as indicated in Table 3.
**Figure 2.** Co-design in the computerized Ordermade WholeGarment® system

**Table 3.** Co-design in the Ordermade WholeGarment® system

<table>
<thead>
<tr>
<th>Customisation in the Ordermade WholeGarment® system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Choice of material</td>
</tr>
<tr>
<td>Choice of colour</td>
</tr>
<tr>
<td>Item and style</td>
</tr>
<tr>
<td>Attachments</td>
</tr>
<tr>
<td>Size (input of body measurements)</td>
</tr>
<tr>
<td>Customisation completed</td>
</tr>
<tr>
<td>Knitting data automatically created by the software</td>
</tr>
<tr>
<td>Customised product displayed in the computer</td>
</tr>
</tbody>
</table>
The ideal scenario is that a customer comes into the shop to examine sample garments, yarn, and swatches that are on display. After the prospective buyer decides to create a customised garment, a design technician on the shop’s staffs take the customer’s measurements and input them into the Ordermade Wholegarment® system (Figure 3). Through a process of multiple choices, a garment is designed and visualized on the screen. The customer selects materials, colours, and structures, and such alternative styles as cardigan, sweater, slipover or other variations (Figures 4-6). As options are entered into the computer, they are converted directly into knitting information, eliminating the need for time-consuming programming of the knit CAD computer. The software automatically produces the knitting machine control instructions.

Although there is customer involvement in the design process, the outcome will not be a free fashion design, as the customer has a restricted range of options. After the client studies the product’s image on the computer screen, further changes can be made. As in the case of the manual co-design process, at this point the customer may still opt not to buy the garment. If the purchase is made, a pre-payment received and the order is transmitted to the production unit.
Figure 4. Style selection in the Ordermade WholeGarment® system

Figure 5. Sleeve length selection in the Ordermade WholeGarment® system
Analyses

The simulation model and modelling method

A model can be understood as an artificial representation of an actual system. It should contain details, but no more than necessary to represent what it stands for. The discrete simulation we constructed employed the process-interaction method, whose basic function is to emulate the flow of an object through a system until it is either delayed, enters an activity, or has been completed. When the object is stopped, time is advanced to the next movement. The flow is a sequential representation of processes, waiting times, or other states that the object may attain in the system. Since each process and event in the model is simulated [28], the model represents the components of a system and their interactions.

Discrete-event models are time-based and their results are a product of the interactions of system components. In the case of the co-design concept, the model consists of the different components in the system and the values for these components. As such, it has seven processes, ranging from choice of style and material to the final attachments, as illustrated in Table 4. The simulations for the two co-design concepts were performed simultaneously. Each simulation represents 200 hours and was repeated 15 times. All process lead times for the final simulation are displayed in Table 4. The simulation begins when the co-design process between the company and the customer is initiated, and concludes at the point of sale (with the customer submitting an order and paying for the purchase). The aim of the model is to compare the two co-design concepts, while factors such as the number of customers entering the shop, the number of shop assistants involved in the transaction, and the number of computer configurators in the store is varied. The simulation was produced by means of the AutoMod™ system Version 11.2, a program for building models and simulating detailed design, materials handling, and manufacturing processes.

Figure 6. Colour selection in the Ordermade WholeGarment® system
Table 4. Lead times in the co-design process of knitted fashion garments

<table>
<thead>
<tr>
<th></th>
<th>Manual co-design</th>
<th></th>
<th>Ordermade WholeGarment co-design</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td>process time</td>
<td>process time</td>
<td>process time</td>
</tr>
<tr>
<td>Style</td>
<td>7</td>
<td>15</td>
<td>11.0</td>
</tr>
<tr>
<td>Material</td>
<td>5</td>
<td>10</td>
<td>7.5</td>
</tr>
<tr>
<td>Neck type</td>
<td>4</td>
<td>8</td>
<td>6.0</td>
</tr>
<tr>
<td>Sleeve length</td>
<td>5</td>
<td>8</td>
<td>6.5</td>
</tr>
<tr>
<td>Size</td>
<td>5</td>
<td>20</td>
<td>12.5</td>
</tr>
<tr>
<td>Colour</td>
<td>5</td>
<td>15</td>
<td>10.0</td>
</tr>
<tr>
<td>Attachments</td>
<td>3</td>
<td>5</td>
<td>4.0</td>
</tr>
<tr>
<td>Total process time</td>
<td>34</td>
<td>81</td>
<td>57.5</td>
</tr>
</tbody>
</table>

a All process times in minutes
b Times for customer co-design process exponentially distributed

In-data for the simulation

The lead-time data is based on information from companies involved in the customisation of fashion products and our own experience with the Knit-on-Demand research project at the Swedish School of Textiles. The shop in the simulation is open to the public for nine hours a day. The 200 hours we have chosen for our simulation correspond to approximately one month of the shop’s retail operations. An exponential distribution is used to model the arrival of customers at the shop at estimated interval of one minute. The probability that a client will start to customise a sweater is judged at 10%. It is also assumed that 50% of those who begin to co-design a garment will buy the product. In order to analyse the performance of the two co-design concepts, some key factors in each are changed in the simulations. In the Manual WholeGarment co-design concept, we have varied the number of shop assistants engaged in guiding clients in the personal design of a garment. In the Ordermade WholeGarment concept, the number of computers in the store is the variable. In both concepts, the number of shop assistants and configurator computers are set to vary from one to three in the different simulation runs. Input data for the simulation are displayed in Table 5.
Table 5. Input data for the simulation in Automod

<table>
<thead>
<tr>
<th>Input data</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation time</td>
<td>200 hrs</td>
<td>The shop is open to the public for nine hours per day. These 200 hours correspond to approximately 1 month of the time the shop is open.</td>
</tr>
<tr>
<td>Customer shop entrance</td>
<td>every 1</td>
<td>One new customer every 1 minute exponentially distributed.</td>
</tr>
<tr>
<td>Simulation repeated</td>
<td>15</td>
<td>The simulation is repeated 15 times.</td>
</tr>
<tr>
<td>Probability of a customer starting co-</td>
<td>10%</td>
<td>There is a 10% probability that customers entering the store will begin to co-design a product. This is not the case with the Internet alternate. The aim here is to examine how many customers will customise a garment over a period 200 hours with a distribution of 1 minute.</td>
</tr>
<tr>
<td>design</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Probability of a customer buying a</td>
<td>50%</td>
<td>There is a 50% probability that customers who begin to co-design a product will purchase it.</td>
</tr>
<tr>
<td>product</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Probability of a customer choosing to</td>
<td>50%</td>
<td>There is a 50% probability that customers who buy a product will also choose to add some kind of attachment.</td>
</tr>
<tr>
<td>add attachment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of shop personnel</td>
<td>1,2,3,4,5</td>
<td>This value varies between 1 and 5.</td>
</tr>
<tr>
<td>Number of co-design systems</td>
<td>1,2,3,4,5</td>
<td>Number of co-design systems Ordermade WholeGarment® available in store.</td>
</tr>
<tr>
<td>Probability that a person in the shop</td>
<td>10%</td>
<td>Unavailable for one day (9 hours).</td>
</tr>
<tr>
<td>staff is unavailable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Probability that a co-design system is</td>
<td>10%</td>
<td>Unavailable for one day (9 hours).</td>
</tr>
<tr>
<td>unavailable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of shop personnel and co-design</td>
<td>5 and 5000</td>
<td>This factor is 5, except for the Internet alternative where the factor is 5000. The intention is to show the power of the Internet option.</td>
</tr>
<tr>
<td>systems</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results of the simulation

To illustrate the results from the simulation, charts were made using the output data. The figures below summarise the results of the simulation. As an example of one of the fifteen simulations, Figure 7 examines the number of customised garments in Manual WholeGarment co-design compared with products created with Ordermade WholeGarment co-design. For Manual WholeGarment the result varies from 146 to 409 garments, depending on whether one, two or three shop assistants are available to assist with the co-design. Similarly, for Ordermade WholeGarment co-design the result varies between 259 and 794 customised products, depending on the availability of one, two or three computers available for customers use.
In Figure 8 we illustrate the situation when a store has five co-design computers available, rather than five salespeople. The result shows that co-design with a configurator is more efficient in terms of numbers of customised garments than the manual co-design option. At the end of 200 hours of simulation, the result was 800 customised products via a configurator and 700 with manual help from a shop assistant. To show the capacity attainable through a configurator and illustrate the difference between the alternative co-design concepts, we have projected the outcomes assuming five personnel in the shop, compared with 1000 configurators. Our intention is to show what happens if the configurator can be accessed through the Internet at a retailing company’s web page.
The results in Figure 9 show a significant difference between the two alternatives. The Ordermade WholeGarment system (in this case the Internet alternative) enables over 8000 products to be customised, compared with less than 1000 for Manual co-design. This rests, of course, on the great difference between the number of in-shop personnel and the almost unlimited access to configurators on the Internet (five versus 1000), and illustrates the vast possibilities the Internet option provides to retailers.

![Co-designed knitted fashion garments](image)

**Figure 9.** Total number of customised garments designed via 1000 computers with Ordermade WholeGarment versus five personnel using Manual WholeGarment

**Comparison of the two co-design concepts**

A problem for customisation of complete knitted garments has been the lack of a co-design interface between the company and the customer that would make the concept more efficient. The two concepts we have compared by means of simulations involve two approaches to customisation: the traditional manual co-design, Manual WholeGarment, a process not unlike olden times when the customer went to the tailor for new clothing. Since it involves interaction between the client and a skilled shop assistant, this type of co-design offers certain advantages, especially since it involves personal contact in a setting where guidance and advice can be given in designing the garment. Manual co-design should not be underestimated; many customers prefer it and feel more secure dealing with a shop assistant. Manual WholeGarment is well-suited for clothes in the higher price range. Stores that already have an established service-minded staff should consider it when deciding on the adoption of a customisation concept. The drawbacks of the Manual WholeGarment process are its low efficiency, since each customer requires individual attention from at least one shop assistant. Serving clients at one time requires a large staff to avoid queues, dissatisfied customers, and lost sales.

Analysis of the two customisation concepts and the simulations indicates the strength of the Ordermade WholeGarment configurator tool. It allows customisation to be performed by the customer without requiring the presence of a shop assistant for each client. The results of the Automode simulations show that a configurator will enable for more clients to customise a garment compared with the manual alternative. However, the simulations don’t show a significant better result for the configurator alternative but co-design via computer by each customer enables for less store personnel and thus lower cost for the company. Co-design with Ordermade WholeGarment can also be perceived by many customers as a positive shopping experience, since it allows them to fulfil their creative impulses and be a designer for one day. The positive effects of this concept are time savings...
in ordering, manufacturing, and delivery of the completed garment. Thus Internet sales may present
the opportunity for a company the future and with an efficient co-design system on its web page to
serve many customers at the same time. One of the main drawbacks of any co-design system is that a
client's measurements that must be taken by shop personnel, a time-consuming process, especially
when many customers need to be served at the same time. One solution may be to let customers
enter their own measurements directly into the co-design system, as many companies already do
today. It may be difficult to do this accurately, some people may resist the process altogether. The
result of our analysis indicates that improvements might be done to make the co-design system more
suitable for the fashion industry. First, we suggest that the co-design process be further developed to
allow customers to input their measurements into the system directly. Second, the number of styles
the system makes available to clients could be expanded. More styles, colours, and materials would
present an exciting shopping experience for prospective buyers. The latter, however, involves a
balancing act, for as is well known in mass customisation, too many options can confuse the customer
and result in a risk of lost sales. Finally, the sale and manufacture of mass customised clothing such
as knitted garments depends on reducing the processes from customer demand to fulfilment of that
demand so that the product can be delivered quickly. Especially important are those processes after
the point of sale, when the customer (who is accustomed to leaving a store with the purchased item)
has paid for the garment and is eager to receive it. It is advantageous if manufacturing and delivery
could be done rapidly in order to reduce waiting time for the customer. The development of the
Ordermade WholeGarment system shows that it is possible to do the time-consuming programming of
knitting machine design options before a client begins the customisation process. The result is
increased efficiency in the production of a garment by expediting the co-design process and moving it
one step closer to customer demand fulfilment, as illustrated in Figure 10.
Conclusion

A co-design tool for knitted fashion products has advantages that simplify the customisation process and reduce delivery time of the completed garment to the customer. Two main benefits of the system are identified in this paper. The first is that customers can do a considerable amount of customisation on their own, without requiring assistance from shop personnel. The second is that the customisation options in the co-design tool are pre-programmed, as is the control information for the knitting machine. Thus, when the customisation process has been completed the garment can be knitted without no delay for time consuming programming. Development of a configurator brings the process a step closer to mass production efficiency in the production of customised knitted garments.

The future of mass customisation of knitted garments looks bright for co-design systems of the kind we have considered. Perhaps stores like Factory Boutique Shima will one day offer clients the opportunity to design a product that is then knitted directly in the store and delivered to the customer within hours. We may see collaborations between fashion retailing companies with knowledge of market demand and a knitwear manufacturer for the development and production of co-designed products. The
technology is already available that will encourage the growth of stores devoted to the mass customisation of fashion products with a minimum of help from shop staff.

Can we say that Ordermade WholeGarment® is successful? Thus far it seems to have served to demonstrate how a computer-based system can be used for mass customisation of flat knitted products. Some aspects of the concept must be improved or altered if the idea is to spread to other retailers or knitting companies. For the system to take hold, there is a need to develop the co-design process to the point where customers do more of the customisation themselves. Internet sales may present the greatest opportunity for the future. With an efficient co-design system on a company’s web site the retailer’s dream of providing personalised service to an almost unlimited number of clients with a minimum of employees may be very close to realisation.

There are also some limitations in the co-design tool Ordermade wholeGarment®. The system is a multiple-choice-system with, at this stage, not so many choices for the customer as desirable; this has to be further developed. Another issue is how to approach body measurements and garment fit in a simpler way. This activity is still a manual, time consuming process that requires help from shop staff especially when many customers need to be served at the same time. Can the customers do this by themselves as shown by other fashion companies? However, this question must be studied and developed more in the future.

Acknowledgements

The authors like to express their appreciation to the sales manager and technicians at Shima Seiki, and to the managing director, designer, and shop personnel at Factory Boutique Shima in Wakayama, Japan. This study would not have been possible without their cooperation and the help of many others at those two companies.

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References:


Sweden.


Paper V

Larsson, J. (2011) Customer perspective on mass customised knitwear, accepted for publication and resubmitted to Journal of Fashion Practice
Customer Perspective on Mass Customized Knitwear

Abstract
Knit on Demand is a research project at the Swedish School of Textiles in collaboration with the knitwear producer Ivanhoe AB in Gällstad and the fashion retailer SOMconcept AB in Stockholm. The background to the project is the unpredictable fashion market where garments are often produced on a forecast and not on actual demand. The essence of Knit on Demand is to let the customers themselves design the garments. Sales started in SOMconcept's store in PUB Huset, Stockholm in September 2009 and ended in December 2010. So far the concept has been analyzed from the retailer's and the producer's perspective, and from their point of view the concept has worked fine even if it needed some adjustments and fine-tuning. This paper presents a description of the customer’s involvement in the design process and how the customer experienced the concept.

KEYWORDS: Mass customization, customer experience, supply chain management, knitwear

Introduction
Knit on Demand is a research project at the Swedish School of Textiles in collaboration with a knitwear producer in the south of Sweden, Ivanhoe AB, and a retailer of tailored fashion in Stockholm, SOMconcept AB. The purpose of the project was to develop and test a new production and logistic solution for agility in customer relations. Initially, the idea was to build a store inside the knitting company’s facilities and equip it with a complete garment knitting machine, a digital design system connected to the knitting machine and a design technician. The concept store was called “Knit in Shop” and the idea was that customers could come into the store, sit down with the design technician, and with the help of a digital design system, create a personalized knitted garment. Figure 1 illustrates the set-up of the store.
When the customer was happy with the design and the technician had guaranteed its manufacturability, the garment would be instantly produced on the complete garment machine and three hours later it would be ready for the customer to pick up. Meanwhile, the customers could go to the other stores in the area and do some shopping or have a cup of coffee or something to eat. The purchase of a garment was supposed to be surrounded by the experience of designing and watching the garment being produced and add value to the garment.

There were supposed to be several positive effects of such a set-up: customers would have personalized knitted garments and hence be more satisfied; no cutting or sewing would be needed; there would be no finished goods inventory and thus no sales on obsolete stock; it would draw customers to the conventional store; and it would increase stockturns, revenue and sell-through. The customer experience was already at this stage considered as a vital selling point, and it was the growing creative group (Florida, 2002) of the society that was supposed to be the customers.

Obstacles included the geographical placement of the store. It was to be placed in an outlet area of Gällstad in the Southwest area of Sweden, known primary for knitwear, inexpensive outlets and frugal people. However, the store never opened in the location where it was originally intended. The investment in a complete garment machine and the additional design system halted the project. The investment was equivalent to ten percent of the company’s turnover, and this was considered unaffordable. In addition, it required precious retail space from the outlet store. Moreover, the complete garment machine was not flexible enough to completely remove the processes of cutting and sewing. Attaching the collar in a post-knitting process was still required, since the collar the knitting machine was able to create was not soft and stretchy enough.
Luckily, SOMconcept AB, which in 2008 was a relatively new business and focused on selling customized fashion in Stockholm, offered their services to sell the customized knitwear. SOMconcept AB had a store in Stockholm where they sold tailored fashion. Their initial concept was that the customer could bring a picture of a garment, another garment or an idea for a design, sit down with the designer and with the available fabrics and have the garment made to order. As long as the customer was satisfied on the first try and only required some measurement adjustments it was profitable to work with this type of set-up. Soon too many customers wanted to change more than just the measurements on the semi-finished garment, but by then the profit was gone. Instead SOMconcept AB started to work with an alternative solution that built on pre-engineered modules. This did not give the customers as much freedom in design, but it kept production costs at a minimum.

Instead of selling the garments in Gällstad it was decided to sell the garments in Stockholm, and instead of a complete garment machine a conventional fully fashion machine was used. It offered enough flexibility and the fully fashion technique suited the type of knitwear that was sold. The customers were offered six different models (Figure 2) in twelve different colors. The price of a garment ranged from 130 € for a slipover to 170 € for a cardigan with contrasting colors and neckplate. The knitwear concept was tested for 16 months in the retail enviroment before production and sales ended. The reason why it ended was that the knitwear manufacturer experienced a high growth rate on their conventional products and could not keep up with their large volume customers. SOMconcept AB now offers customized jeans, chinos, belts, jackets and suits.

![Figure 2. Offered models](image)

Design of customized garments is different from design of conventional garments. There are two design processes; the first one is by the company that creates a design that is flexible enough to handle most customers’ requirements. At the same time the garment has to be producible so that it is possible to manufacture the garment at a reasonable price (Cross et al., 2009). Included in the first design process is the development of the configurator that the customer uses to design the garment. The configurator usually consists of a design system and a feedback tool that visualizes the choices the customer has made. This feedback tool is necessary in order to help the customer remember the choices she has made. The average customer is not used to keeping a lot of choices in mind and she should not be required to do that. In this concept,
since there was a limited budget, a simple configuration tool was used. It consisted of the different models in each of the sizes and swatches of fabric.

The second design process is the customer's design. In this process the customer designs or configures the garment so that it fits his or her preferences. The customer tries on a size sample and decides on size adjustments, model and color preferences, and added accessories. This paper focuses on how the customer experiences the second design process, from the point at which the customer discovers the concept until the delivery of the finished product and a possible re-buy.

**Purpose of paper**

There is little literature about why people buy customized products and how they experience the design and purchase process. On close topics such as size issues and made-to-measure there is more written. Oliver et al. (1993) concluded that lighter men of average size, when buying made-to-measure garments, choose more fashionable colors and fabrics than bigger and taller men. Big and tall men are on average more dissatisfied with the service at the retailer and especially with fit. These men have been left out of the fashion market because of their size (Shim and Kotsiopulos, 1991). Bickle et al. (1995) concluded that a significant amount of jeans customers could not find the right fit.

Since the possibility to customize garments is a rather new phenomena it may be suggested that customer who choose to do so are fashion innovators or opinion leaders. According to Workman and Johnson (1993), fashion innovators have a greater need for variety than the average fashion customer, hence mass customized products may tickle their fancy. Rogers and Cartano (1962) describe an opinion leader as somebody who introduces new work methods in a society, or somebody who the society turns to for advice. For fashion that would be somebody who introduces new fashion in a group of people or consumes more fashion than the social context.

The owners of a few businesses providing customized garments suggest that customers buy them for basically three reasons: they cannot find the fit they want; they cannot find the design they want; or they cannot find the function they want. Not finding the right fit, design or function may include several aspects. The size may be wrong because the waist is too small or the arms are too long, but it may also be a problem of style if that particular silhouette is out of fashion. The same goes for design and function. SOMconcept AB has solved these problems in the following ways:

- **Fit:** The customer tries on a standard size and from that it is decided whether it needs to be changed or not. The length of the arms, legs and the body can be adjusted and also the cut of the garment.
- **Design:** The customer chooses from a number of fabrics, yarns and trimmings. For example the garments can be fitted with contrasting
colors on the cuffs and on the collar and contrasting fabric on the neck plate.

- Function: The customer can add or remove pockets or choose different trims.

The purpose of this paper is to analyze the concept from a customer perspective, from the discovery of SOMconcept AB and Knit-on-Demand until the eventual purchase. This leads to the research question:

*What factors are crucial in the customer’s experience of buying a mass customized garment?*

### Theoretical framework

#### Mass customization

Mass customization as described by many authors (Pine, 1993, Da Silveira et al., 2001, Tseng and Jiao, 2003, Gilmore and Pine, 1997) indicates a marrying of economies of scale with economies of scope with the aim of profitability.

There are several studies describing how to configure a supply chain to suit mass customized products (Ulrich et al., 2003, Tseng and Jiao, 1996, Franke and Piller, 2002). Most customizable products build on pre-engineered modules; this has several benefits such as known lead-times, a certain level of quality, and easily calculated costs.

From a supply chain perspective mass customized garments are promising, since only what is sold is produced. There would be zero garments made on forecast, and thus there would be no risk in inventory of ready made goods and also no price markdowns. The company also receives payment from the customer before it has produced the product, and the return rates are very low. Among the Swedish companies producing mass customized garments, the return rate is around one percent (Larsson, 2009).

From a marketing perspective mass customization can help to strengthen a brand as long as: 1) the configurator is easy to understand; 2) price is updated as the customer configures the product and 3) there are default products for the customer to start with (Dellaert and Stremersch, 2005).

#### Choice and mass confusion

As Dellaert and Stremerch (2005) conclude, mass customization can strengthen a brand as long as the steps in the design process are easily understood by the customer. In this process the customer chooses from a set of pre-engineered modules. When all the modules are chosen, the garment is ordered, produced, and delivered to the customer. There are five steps in this design process design (illustrated in Figure 3).
One challenge for both the customer and the company that is selling mass customized products is that the customer has to remember the choices throughout the design process while combining it with more choices to build their garment. During the design process the customer creates an image of the garment, an image that she keeps and might adjust until the final delivery. It is the company’s challenge to make sure that the image of the garment that the customer creates is as equal as possible to the ordered garment once it is ready. When the company succeeds, their customers will be happy; if they do not, the customer might not accept the garments. It is notable that Swedish consumer laws state that if a customer has specified the product and the supplier has made it according to the specifications, the customer has no right to return it (Konsumentverket, 1990).

Generally papers that are written about configuration tools suggest that there should be a digital product configurator involved in the process (Piller et al., 2003, Franke and Piller, 2002, Cross et al., 2009, Larsson and Peterson, 2007). Store staff indicate that it is easier to sell jeans having a digital feedback tool than the knitwear without it. It was not possible to build a digital configurator system within the budget of the project, so instead, there is a manual system where the store staff guides the customer through the configuration process. There are in total close to 100 million possible combinations of the garments, which might seem overwhelming. If the customer is confused by a wide assortment, it might be due to perceived complexity and not the actual complexity (Huffman and Kahn, 1998). However, the customer does not have to choose among all of the options. In the design process the customer makes up to ten choices, but in each step of the design process there are only a few choices to consider. The maximum number of options in one design step is the twelve colors the customer has to choose from. Additionally, customers who define themselves as fashion innovators desire a large variety of products and choices (Workman and Johnson, 1993).

Depending on the customers and their tolerance of ambiguity (Furnham and Ribchester, 1995), they will either feel safe or insecure in the design process. The insecure feeling is generally referred to as mass confusion (Piller et al., 2005). For the customer with a low tolerance for ambiguity it would be convenient to have a visual feedback tool that helps the customer remember the choices. Schwartz (2004) claims in his book, *The Paradox of Choice: Why More is Less*, that too many choices in the offline world confuses the customer and leads to lost sales. He also suggests that the same applies to the online world. Chris Anderson (2006) on the other hand, claims in his book, *The Long Tail Economy: Why the Future of Business Is Selling Less of More*, that it is simply a question of...
how the options are presented that makes choice good or bad. Huffman and Kahn (1998) have analyzed how people react to variety and how variety is best managed. They conclude that it is the company's task to educate the customer on the variety, and they can do so in basically two ways: attribute-based presentation or alternative-based presentation. Most people prefer the attribute-based presentation where the customer explains how the product should be configured; then the product is chosen from a large assortment by the shop assistant and presented to the customer. In the alternative based presentation the customer is presented to all the alternatives and configures the product. Interestingly, customers are equally satisfied with the end result from both methods. This conclusion is also supported by Kurinawan et al. (2006). Huffman and Kahn (1998) also conclude that when companies fail to educate the customers about the alternatives, the customers may delay purchasing or leave empty-handed in a state of "mass confusion". This is also supported by Boyd and Bahn (2009). The same authors demonstrate that if an assortment is well presented, customers prefer a large variety of products. The production manager in the Knit on Demand project concludes the discussion on whether choice is good or not:

"You cannot sell the black one if you don't have the turquoise one" (Ulf Göthager, Ivanhoe AB).

**Customer experience and authenticity**

Customers use all five senses when they are shopping: sense, sight, hearing, touch and taste. The more senses that are engaged while shopping, the more memorable the experience. Gentile et al. (2007) define the customer experience as follows:

"The customer experience originates from a set of interactions between a customer and a product, a company or part of its organization, which provoke a reaction. This experience is strictly personal and implies the customers’ involvement at different levels (rational, emotional, sensorial, physical, and spiritual)."

Gilmore and Pine (2007) write that customers are increasingly shopping not for a specific product but for an experience, and they want this experience to be authentic. Lewis and Bridger (2000) writes that authenticity is a crucial factor for attracting what they refer to as the “New customer” The new consumer is described as being involved, individualistic, well informed, independent and seeks authenticity rather than conveniency in most of their major purchases. Similar to how Florida (2002) described “The rise of the creative class”. These customers want their shopping experience to be real, and they want it from transparent sources so that the product is guaranteed to be authentic. This is not the kind of authenticity offered by slick marketing people who blur the boundaries between what is authentic, what is not and creates stories around products or services (Lewis and Bridger, 2000).
Pine and Gilmore (Pine and Gilmore, 1998) also suggest that people are willing to pay more for poor service as long as the experience is worth it. One example is the Karaoke taxis in which customers pay for making that extra turn around the block just so that they can sing one more tune. They arrive later at the venue, with less money in their pocket, but they are still more satisfied then if they had taken a normal taxi. This partly explains why the customers in the Knit on Demand project who do not really need to buy made-to-measure garments are still willing to wait longer and pay a higher price for a product that most of them could buy off the shelf; they want the experience of designing their own unique garment.

An experience can be described across two dimensions. The first corresponds to customer participation and the second describes the customer’s connection to the experience. A customer can either passively or actively participate in an experience. Passive participation could be to see a movie, whereas active participation may be to go skiing. A concert may seem like a passive experience but a rock concert for example, requires active participation from the audience to become an experience. The second dimension of an experience describes the connection between the customer and an event. Somebody could be in the event, for example driving a really fast car (immersion) or looking at somebody else driving a really fast car (absorption). Figure 4 illustrates the two dimensions and sorts them into four realms, entertainment, educational, aesthetic and escapist.

![Figure 4, The Four Realms of Experience (Pine and Gilmore, 1998)](image)

In the entertainment realm experiences such as TV-shows and going to the cinema are found. During such an experience the customer is passively watching actors performing. An educational experience requires the customer to actively participate in an event such as taking a skiing lesson. An escapist event immerse the customer and lets the customer actively affect the experience such as off-piste skiing or something else that disconnects from everyday life. In the aesthetic experience the customer is immersed but has little effect on it, like a visit to an art gallery. Usually,
experiences that include all the aspect are favourable (Pine and Gilmore, 1998).

**Method**

This paper has a case study approach and is based on mainly three sources of information from which both qualitative and quantitative data is collected. Yin (2009) describes a case study as “...an emperical inquiry that: investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident.”

The first source of information is a qualitative questionnaire, the purpose of which was to analyze how the customer experiences the configuration process and what type of customers are buying the garments. It is based on the configuration process for mass customized products suggested by Franke and Piller (2002) (Figure 5). Each of the questions are related to one or several steps of the configuration process.

<table>
<thead>
<tr>
<th>Communication</th>
<th>Exploring</th>
<th>Configuration</th>
<th>Waiting and delivery</th>
<th>After-sales</th>
<th>Re-buy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain of customer attention, first contact and information</td>
<td>Detailed information about possibilities, e.g. design options</td>
<td>Selection of design measurement and collection of customer data</td>
<td>Notification of delivery date, delivery or pickup of garment, first try-on</td>
<td>Information e.g. about new models, customer feedback</td>
<td>Use of existing customer data and profile for re-orders</td>
</tr>
</tbody>
</table>

*Figure 5, steps in the purchase/configuration process of a mass customized product (Franke and Piller, 2002)*

In addition to the questions about the configuration process, three questions (Goldsmith et al., 1999) are asked to define the characteristics of the customer: Is the customer a fashion innovator, a fashion follower, or a late adopter? The questions concern consumer shopping behavior, spending, and general interest in fashion. All thirty customers were contacted and asked if they wanted to participate in the interviews. Those who were willing to participate were contacted via telephone. Eight customers were interviewed and each interview lasted for approximately 30 minutes.

The second source of information is the order sheets from the customers. From the order sheets information regarding sizes and size adjustments have been analyzed. There were in total 37 order sheets from September 2009 to December 2010 from 30 different customers. There is a risk that customers who do not fit into standard sizes were self-conscious about their size. Therefore, in order to secure the integrity of the customer data, information about size and size adjustments were separated from personal information such as name and telephone number.

The third source of information is the design process, which has been analyzed, both passively from an observing point of view and actively by participation. The store staff was also interviewed about the design process and how they assisted the customers in designing the garment.

Since this is a business concept and the development of each part is done together with the companies, there will also be results and conclusions from those sessions.

In order to make the results from the risk analysis reliable, **multiple source of evidence and data triangulation** approach has to be used. There
are four types of triangulation; data-, investigator-, theory- and methodological triangulation. For this case study mainly data triangulation is used and also investigator triangulation. When pursuing triangulation of data there are conditions that have to be fulfilled. For true triangulation, upper portion triangulation, data from different surveys are compared and conclusions are drawn from that. For lower portion triangulation the conclusions from different surveys are compared (Yin, 2009). In this case study a mix between upper- and lower portion triangulation is used.

Since the data set from the beginning was not very extensive, it is difficult to prove the results statistically. The data set is, however, large enough to show tendencies and to draw some conclusions.

**Results**

*Purchasing and design process*

It is often serendipitous that customers find the store and the Knit-on-Demand concept. Most customers more or less stumbled upon the store when they were out shopping, and some had read about it in a magazine. The customers are mostly ordinary customers but with some extra-ordinary needs, like long arms compared to the torso or a narrow torso compared to the length of the garment. They do, at first glance, seem more fashion conscious than the average person, since they have chosen to design a personalized garment and pay a rather high price for it. However, when asked about their consumption habits, it appears that they are about as interested in fashion as their social context and on an average they were not fashion innovators but rather fashion followers. Most important for these customers are the fit, aesthetics, and the quality of the garment. Price is not an issue for the average customer as long as they like the garment and they know the garment will last in shape and color.

The customers found it relatively easy to design their garment, due in great part to the friendliness and helpfulness of the store staff. Even if some felt a bit of initial confusion, all the customers felt comfortable when designing, again thanks to the store staff. Visualization of the end product helped a lot because of the sample garments, but some customers would have preferred a digital visualization of the garment to help them remember their choices. About half of the customers wanted more design options but they did not specify what they would like to change and why.

The preferred lead-time is between one and two weeks, but some customers had to wait for several months for their garment. Surprisingly, none of the customers could specifically tell the lead-time or the price of the garment. They did, however, talk about the quality and the fit of the garment and the excellent service they were provided in the store. Georgio Armani once supposedly said, "Price is forgotten within a week; quality is never forgotten," and in the context of this paper, he probably had a point. Customers also intended to use the Knit on Demand garments longer than their other garments since they like them better and felt that the quality was better than other garments that they owned. All the customers also thought it were a great experience to design their own garments and they will definitely do it again, either with jeans, suits or with knitwear. The
customers used words like "awesome", "cool," and "great experience" when asked to describe their experience. Even if the customers understood that there was a chance that some other customer would order a similar garment, they still enjoyed the sense of uniqueness that the design process gave them. Even if they did relatively few changes to the sample garments, they still felt like they had designed their own garment. Perhaps the strangest answer came from the customer who had received a garment that was too small to wear but was very happy and satisfied with the services anyway.

**Sizes**

One of the reasons that the customers gave as to why they were buying customized garments is that they do not fit into the standard sizes. In table 1 the result from the analysis of the customer size data is presented. The size data comes from the size of the garments they have bought and the adjustments that have been done to the garments.

When a customer buys a customized garment, the first step in the design process is to try on a sample garment in one of the standard sizes from extra small to extra large. A medium garment fits a 180 centimeters tall man and has a straight and narrow fit. Then the length of the body and sleeves are adjusted in steps of minus or plus two centimeters. The average size adjustment was +1,13 cm on the body length with a standard deviation of 3,48 and +1,64 cm on the sleeve length with a standard deviation of 2,47. Looking at these figures suggests that most customers would fit into the standard sizes anyway and that they are buying garments for other reasons than fit, perhaps vanity. However, some customers change only the body length, only the sleeve length or both body and sleeve length (Table 1), and when dividing the customers into groups the result is somewhat different.

<table>
<thead>
<tr>
<th>Type of change</th>
<th>Average (cm)</th>
<th>Standard deviation (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only sleeve</td>
<td>1,8</td>
<td>2</td>
</tr>
<tr>
<td>Only body</td>
<td>-0,3</td>
<td>4,63</td>
</tr>
<tr>
<td>Both sleeve and body</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sleeves: 3,84</td>
<td>Body: 3,84</td>
</tr>
<tr>
<td></td>
<td>Sleeve: 2,51</td>
<td>Body: 2,76</td>
</tr>
</tbody>
</table>

*Table 1. Average adjustment of garment measurements*

When broken down into groups, depending on the number of changes in fit, the picture changes. The first group, 41 percent of the customers who only make one change, adjust within the size ranges that can be found in any store. Most of these customers would be fine with a standard, non-customized garment. However, the standard deviation is quite large, which suggests that there are customers who have made relatively large adjustments. The second group, 38 percent of the customers, change both sleeve and body length. On the other hand, their measurements are on an average outside any existing standard, which means that they cannot find garments that fit them in traditional stores. Even the standard sizes that are
longer and narrower still would not help these customers since as much as
plus six centimeters is not an unusual adjustment. The third group, 21
percent of the customers, did not make any adjustments at all.

From the producers perspective customizing knitwear is challenging,
since they cannot afford any mistakes. One of the most challenging aspects
is to get the size exact. The production manager of Ivanhoe AB has a
mantra that goes:

“When a carpenter saws a plank to the length of one meter, it becomes
one meter. But when a knitter makes one meter of knitted fabric, it
becomes anything but one meter.”

However, as long as the size of the garment is too small, the problem
is easily solved with a steam-doll that can add a few sizes by blowing up
the garment.

**Discussion**

Some of the results of the investigation were a little unexpected. For
example, the average customers did not consider themselves as fashion
conscious or to be a “fashion innovator” as defined by Goldsmith et al.
(1999) or opinion leaders as described by Rogers and Cartano (1962), even
though they were willing to spend up to 170 € for a cardigan. Anybody
willing to spend that amount of money on a garment would be considered
very fashion conscious but they did not. They rather considered
themselves to be fashion followers. This is, however, compared to a social
context where it might be considered normal to spend quite a lot of money
on clothes or not to be concerned about the price of the garments at all.
Moreover, the store is placed in a department store and people who
generally shop there are rather wealthy and perhaps do not consider the
price of the garment, as long as the garment lives up to the expectations.

According to the customers, the main reasons why they are buying
customized garments are fit, aesthetics and quality of the garment. This
correlates well with what the store staff and other retailers of mass
customized products believed was important when selling mass
customized garment, which is fit, form and function. It has to be
remembered that many of the customers have not owned a garment that
actually fit them in many years. The sweaters they are used to have been
too wide, too short or too slim, so finally owning a garment that fits them
perfectly might be an experience large enough to pay what others might
consider high price for a simple knitted garment. Fit was also one of the
main reason why customers purchased customized knitwear. It was also
one of the reasons male customers felt discontent about the service in
conventional fashion stores (Shim and Kotsiopulos, 1991). Seventy-nine
percent of the Knit on Demand customers did adjust the fit of the garment,
and of these about half changed it to such an extent that no Swedish
standard sizes would have fit.

Gilmore and Pine (2007) and Lewis and Bridger (2000) claim that the
shopping experience and the authenticity of the concept are becoming
increasingly important for customers. The Knit on Demand project fits very well into what could be described as authenticity with transparent sources; transparent not only for the customer, but also transparent for the producer who knows the end consumer by name and body measurements. In general the customers described the buying and designing process as a “great experience” and all of them were impressed by the helpfulness of the store staff and assistants. In fact, the two things most customers kept referring to was the experience of designing their own garment and the service provided by the store staff. Service and shopping experience are also, according to the store staff, among the most important attributes of the concept.

What further helps to build the customer's excitement about the concept is the store environment that adds authenticity to the shopping experience with seamstresses operating sewing machines in the store and measurements taken the traditional way. In that way a sense of uniqueness is delivered to the customer, which probably helps to build the authenticity. The sound of the sewing machine in the store, the tactile experience of choosing between different fabrics and visualizing the end result also engage many senses and help to further build the experience and involves the customer in the purchase on a different level than in a conventional store. A customer buying a customized garment would theoretically end up in several of the experience realms (Pine and Gilmore, 1998). The experience may be educational since the customer does learn something about the product in the interaction with the store staff. It may also be an experience of the escapist variety that lets the customer escape from reality and find entertainment in his or her fantasy, as well as being and esthetic experience since the customer designs the garment.

One important aspect of an authentic shopping experience is involvement in a purchase. Customers get involved in a purchase mainly for three reasons (Lewis and Bridger, 2000); one, they want to save time; two, they want to gain personal advantage; three, they want to increase their enjoyment. Customising an own garment does not save any time for the customer since it takes more time than for conventional garment in the order fulfillment process. However, most customers are changing the measurements of the garments so one reason they get involved is for personal advantage, the personal advantage being that they receive a garment that fit their preferences on fit, form and function. It is also reasonable to guess that customer enjoy the customisation process since they described it as “awesome” and “cool”.

According to Piller (2003) a digital visualization tool would help the customer to remember their choices, but only a few customers believe that they would have been helped by it. Most customers were very satisfied with the sample garments and the service provided by the store staff. Visualization tools are helpful when the customer needs to remember several changes during the design process to avoid confusion. It was suggested by Furnham and Ribchester (1995) that people’s tolerance for ambiguity would be an obstacle in the purchasing process; some people have higher tolerance for ambiguity and others have lower. As an example, fashion innovators desire more variety than the average customer to be satisfied (Workman and Johnson, 1993), which may suggest that they are
more tolerant for ambiguity. Some customers were more comfortable in designing than others, but again, the service provided by the store staff made the customer feel safe and secure about the choices they had made. It helped that the variety was presented in attribute-based form, which means that the customer expresses her wishes and is then presented to a variety of choices based on that wish. Dellaert and Stremersch (2005) is on the same track but they take it one step further; they conclude that the customer should be presented a default model that they can use as a starting point when designing, and maybe, in some cases, as a rendezvous point in the design process. In the Knit-on-Demand store these methods are utilized in the form of different sample garments that the customer can look at and choose among, and the store staff assists the customer in their design process. One part of the design process is making customers feel more confident about themselves and the choices they make. Huffman and Kahn (1998) write that by educating the customer, companies that decrease confusion among customers have happier customers in the end. According to the customers, the store staff is proficient in explaining to their customers how to make the correct choices. In fact, customers did not experience much confusion at all and in fact, about half the customers wanted more choices, these customers could be the fashion innovators that Workman and Johnson (1993) are referring to. These customers does not think of themselves as fashion innovators but the way they desire more variety reveals them as fashion innovators.

Schwartz (2004) (who said choice is bad) is in this case wrong and Anderson (2006) is right when he claims that as long as it is presented in a good way, choice is good.

The properties of knitwear will have an effect on the customers’ satisfaction and thus the total experience. Since knitwear is flexible, it will be somewhat difficult to make to measure. However; since it is flexible, it will not be that obvious for the customer if the ready made garment is not correct in size to the millimeter. The flexible properties of knitwear are likely one of the reasons that mass customized knitwear is not in such a demand as customized woven garments; a standard knitted garment is simply flexible enough to take care of many of the non-standard size or shape customers.

Conclusion
The experience of the design and purchase process of a personalized garment is unique for each individual customer but can be generalized to understand the crucial elements in the experience. These elements can be divided into two parts: the product characteristics part and the amusement part.

The most important aspect of the product is according to the customer fit, then aesthetics and last quality. Over seventy per cent of the customer adjusted the fit of the garment and half of those adjusted it to sizes that are not covered by standard sizes. Price of the garment and delivery time was secondary, in fact, most customers had forgotten about price and delivery time at the time of the interview. About half of the customers wanted more design options and the other half were satisfied with the available variety.
Even though the customers did not consider themselves to be fashion innovators their request for more variety indicate that there are elements of fashion innovativeness. The quality element is crucial for the “post experience” since the customer forgets about price and delivery lead-times almost immediately but is reminded about the quality several times every week.

The most important aspect of the amusement part of the shopping experience is the service offered in the store by the store staff. When broken down, the service elements, including the excellent assistance provided in the design process, made the customer feel comfortable to design and buy a mass customized garment. When seen in the perspective of Pine and Gilmore (1998) the experience of buying a mass customized garment includes several of the realms which makes it a desirable experience for the customer. The amusement part also includes the authenticity element, that the customer feels that what they are buying into is for real and not just a surface, there is a greater sense of involvement in a purchase of this kind. Customer get involved mainly because of fit reasons but also because of the design experience. For this particular customer group who did not fit into the standard sizes, it was a positive experience to have a garment that finally fit them.

References


Paper VI

The Knit on Demand Supply Chain

Abstract: As customers’ buying behaviour develops towards a more differentiated taste, so must the companies develop their offerings. The demand for variety might soon become unmanageable, and several companies are preparing for this by adopting the concept of mass-customization. One of these projects is called Knit on Demand and is being conducted by the Swedish School of Textiles in close collaboration with a knitting company and a retailer of tailored fashion in Stockholm. Production and sales of customized products impose logistical challenges for the companies involved, such as the one-piece flow through almost the entire supply chain and the demand for short lead-times in an otherwise slow environment adding to the cost of manufacturing mass customised garments. Customization has logistical benefits such as minimized inventory; hence, high inventory turnover and the possibility of fast response to meet customer demand have created an agile supply chain.

Keywords: mass customisation; supply chain management; fashion logistics; knitwear; demand driven
# Introduction

In Western society there is an abundance of choices. As long as your body fits into the standard sizes, you can find any shirt, pants, sweater or jacket you wish for. The problem with the abundance of choices is that it also creates an abundance of products in the market, which in the end leads to markdowns and obsolete inventory. Of these sales approximately 35 percent of the assortment bought up-front, 30 percent of the short term buying and nine percent of the replenishment buying goods has to be marked down at the end of the season (Mattila et al., 2002). Obviously, this is very good for the customer, since they will not have to pay the full price for the garments, but bad for the fashion companies. Some authors (Cerruti and Harrison, 2006) suggest that the reason for the overstocking in the market is the short lifecycle of fashion garments, and that the fashion companies are trying to respond to the diverse customer demand by offering everything. It might also be due to long leadtimes as a result of outsourced production (Mattila et al., 2002). Yet another reason for overproduction could be that it is less expensive to have one extra product in stock than to lose one customer due to low service level. Whatever the reasons, given all the extra garments for which no one is willing to pay full price, it is a significant challenge, and the problem has several solutions.

One solution to the problem of abundance and overstocking is to produce only that which the customer wants. This would require either a state of the art forecast tool that is 100 percent correct or on-demand production. Since that forecasting tool does not really exist, the only option left is to produce on demand. In order to test on-demand production a project called Knit on Demand was carried out at the Swedish School of Textiles in close collaboration with a knitwear producer, Ivanhoe AB, and a retailer of tailored fashion, SOMconcept AB. The original idea was to "...demonstrate a production method for knitwear that may strongly influence the ability of the fashion industry to meet new demands for agility in customer relations" (Larsson, 2009).

The result of the project is a business concept where the customers themselves are allowed to, within limitations, design or customise their own knitted garment, which is then produced at Ivanhoe AB in Gällstad in southern Sweden. Sales started at SOMconcept in Stockholm in September 2009. The project is an example of mass customisation business concept. Mass customisation was described by Pine (1993) as the ability to produce individualized garments at near mass-production efficiency. It could be seen as a response to the abundance in the market and a way for the companies to decrease lost sales (Piller and Müller, 2004, Huang et al., 2008). However, few traditional fashion companies have explored and taken advantage of mass customisation; instead, new businesses have popped up such as Tailor Store AB and SOMconcept AB. Thus it could be suggested that mass customisation is not only a result of the fast fashion industry's short lifecycle and the abundance of products in the market place, it may also be a response to other dynamics in society such as the "rise of the creative class" (Florida, 2002). Moreover, some customers are looking for experiences when they purchase products, and designing a unique garment might be that experience (Gilmore and Pine, 2007, Pine and Gilmore, 1998).
The supply chain of a mass customisation system looks slightly different compared to a supply for mass production system. To begin with, it reacts on true customer demand and not on forecasts. It also has a well-defined decoupling point after which no changes can be made and it operates in a one-piece flow where every product has a dedicated customer waiting for them in the end of the flow.

Previous work on mass customisation of fashion mostly addresses how customers prefer to buy customised products (Ulrich et al., 2003) and how customer experience the customisation process (Huffman and Kahn, 1998). There is little literature on supply chains for mass customised fashion in general and on mass customised knitwear in particular.

The purpose of this paper is to present the concept Knit on Demand from a supply chain perspective. It is presented from the three main topics of the project: design, technology and logistics. Thus a definition of supply chain management is needed (CSCMP, 2011):

Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies.

This definition is chosen because it encompasses all the activities in the supply chain and it also includes the customer.

2 Theoretical framework

Supply chain processes
On part of the purpose of the Knit on Demand project was to develop a solution to “...meet new demands for agility”. This suggests that agility is an important part of the concept. Supply chains for mass customised products must respond quickly to diverse customer demand. Mass customisers such as Nike, SOMconcept and Tailor Store have a lead time promise of about three weeks depending on the available production capacity, and these companies offer the customers hundreds of billions of combinations. In literature, such supply chain capabilities are often referred to as agility (Christopher, 2000, Harrison and van Hoek, 2008, Mason-Jones et al., 2000a). The agile supply chain reacts to true customer demand rather than relying on the distorted picture of the future created by forecast tools (Christopher, 2000). Not only does it react on true demand, it also benefits from and thrives in a volatile marketplace (Mason-Jones and Towill, 1999). The concept of agility originated in flexible manufacturing systems that extended from the production to incorporate the entire organisation (Christopher and Towill, 2001). As in the the lean concept, agility is characterised by its focus on customer value in all processes and its ability to develop flexible and responsive processes (Harrison and van Hoek, 2008). According to Harrison and van Hoek (2008), four parameters enable the agile supply chain. First, the supply chain should be market responsive. Secondly, it should be viewed as a network rather than a chain. Thirdly, the business capabilities of each of the partners in the supply chain should work to create synergies with each other. Fourth, the supply chain should use information and communication technology to
share information in a virtual network. The winning order for these processes does not necessarily have to be cost; it may be flexibility (Christopher and Towill, 2001). However, lean philosophies also have similarities with mass customisation. Characterising for lean philosophies are waste reduction, a steady flow of material an information and producing according to customer needs (Liker, 2004).

It must be remembered that lean and agile do not conflict with each other, but rather offer support for each other (Andersson et al., 2006). When the trade off between flexibility and productivity is done, the driving force behind the business concept, which is economies of scope, has to be considered. After the decoupling point the customer no longer has any chance of changing the configuration of the garment. This is also the customer order point and when the customer pays for the garment.

The one piece flow is characteristic of supply chains for mass customised garments. According to Miltenburg (2000), the one piece flow is best suited for u-shaped pull production systems paced by takt time. It is suitable for producing medium volumes of many product variants in cells with an even flow of products. It is flexible and has a high quality output and short throughput times. It is also considered to be one of the most powerful waste reduction tools and decreases the total lead-time of the product, since no products are stored between processes (Liker, 2004).

Mass customisation

The notion of mass customisation as a production paradigm appeared in the late 1980s. It emphasizes the need to provide unique products to meet customer’s individual needs (Pine, 1993, Pine et al., 1993, Feitzinger and Lee, 1996). Gilmore and Pine (1997) describes four types of customisation: adaptive, cosmetic, transparent and collaborative customisation. Adaptive customisation is when the company provides the customer with standard parts and lets the customer do the customisation. Lego is a good example of adaptive customisation. Cosmetic customisation leaves room for only changes to the surface of the product, e.g. product but with different packaging options such some breweries offering customized labels on their beer. Transparent customisation does not offer any changes in the appearance of the product but the properties are changed. For example, a pair of glasses looks the same no matter what the strength. Collaborative customisation is the highest level of customisation and it requires a close dialogue with the customer in which the customer articulates his or her needs. Examples of this are tailored product such as shirts, shoes, and suits. It is often is regarded by purists as the true type of customisation. Salvador et al. (2004) categorises mass customised products into two supply chains, one for hard customisation and one for soft customisation. Hard customisation is what Gilmore and Pine (1997) refers to as collaborative customisation. Soft customisation would be adaptive customisation and transparent- and cosmetic customisation is somewhere in between. Characteristic for hard customisation is rapid response to customer demand with a high level of customisation. Contrastingly soft customisation has longer lead-times and lower customisability (Salvador et al., 2004).

In supply chains for mass customisation postponement and modularisation is often central (Mikkola and Skjott-Larsen, 2004). By postponing value adding activities to the point were demand is more certain demand related risks can be reduced (Manuj and Mentzer, 2008). For mass customisation systems Rudberg and Wikner (2004) refers to this point as the customer order decoupling point (CODP).
Modularity and product platforms are also characterising for mass customisation (Mikkola and Skjott-Larsen, 2004). Muffatto and Roveda (2002) describes a product platform as: “...a set of subsystems and interfaces intentionally planned and developed to form a common structure from which a stream of derivative products can be efficiently developed and produced”. The aim of both modularity and postponement is to keep product commonality as far down streams as possible in the supply chain and to separate the customisation of the product with the manufacturing of standard components (Mikkola and Skjott-Larsen, 2004).

**Knitting technologies**

There are a number of available flat knitting techniques. All of them build on the same foundation, two knitting beds in a inverted V-position. The most basic knitting machines, cut and sew machines, are capable of knitting panels that later have to be cut into garment pieces. Fully fashioned and integral knitting machines are somewhat more advanced and are able to shape-knit the garment pieces and add pockets, thus reducing waste of yarn and cutting time. The most advanced complete garment machines knits the entire garment in one piece, thus totally eliminating the need for cutting and sewing (Choi and Powell, 2005, Hunter, 2004). Figure 1 illustrates the different available knitting technologies.

**Figure 1** Different knitting technologies

<table>
<thead>
<tr>
<th>Cut and sew</th>
<th>Fully fashion/Integral knitting</th>
<th>Complete garment</th>
</tr>
</thead>
</table>

3 **Methods**

In this paper a case study method has been used. Case studies are powerful tools when it comes to mapping real life situations where the boundaries between the studied object and its environment are blurred (Yin, 2009). A supply chain is a good example of such an object. It is also welcomed to try to use different methods than strictly quantitative in logistics research (Näslund, 2002, Ellram, 1996) In this paper
data from two case studies have been used. The results from the case studies have been triangulated to create reliable facts (Jick, 1979).

The first case study was conducted during spring 2010, after sales had been going on for seven months. The purpose with the case study was to map the Knit on Demand-supply chain. It was mapped using the "value stream mapping" technique, which is a method developed in order to find and eliminate waste in production flow (Hines and Rich, 1997). The study begins with the customer entering the store and purchasing a garment. It then follows the order back to the customer order decoupling point (CODP) where the order becomes a garment. The study continues through the final delivery to the customer.

The second case study was conducted during December 2010. Each purchase of a customised knitted garment was analysed regarding customisation of measurements. These measurements was then compared with the standard size tables for Sweden. There were in total 37 orders from 30 customers, the study includes all garments purchased from SOMconcept and spans from September 2009 to December 2010. The project ended in December 2010 due to capacity constraints at the manufacturer.

This paper does not consider purchasing and delivery of raw materials or strategic planning, since the supply of raw material to the customized knitwear is taken from the inventory that supplies ordinary production

4 Results

This chapter presents the order fulfilment process, from order entry to the final delivery of the product. Figure 2 illustrates the Knit on Demand supply chain.

4.1 Ordering processes

A customer order triggers the system, and it begins with the customer design process, which starts when the customer enters the store and decides to buy a customised knitted garment. The customer is then guided through the steps of the design process (Figure 3) by a tailor and allowed to change the garment based on four parameters; namely, model, fit, colour and details.
Within these four parameters there are additional steps, so the customer goes through nine design steps in total. It is a manual system which means that there is no visual feedback for the customer except for the garments in the store and the swatches of fabric. The tailor has to make sure that the customer understands what the end result will look like. If the image the customer has created of the garment does not closely resemble the end product, the customer might not be satisfied. When the customer is satisfied with the design, it is specified in an Excel document and sent to the manufacturer by e-mail and the order is confirmed by the producer.

Knit on Demand—customers have six different models to choose from (Figure 4). Customisation options include six styles, 16 different colours, stripes and contrasting fabrics (neck plate) and different buttons.

**Figure 4** Garment styles

Each garment is made to measure using a system where standard size garments are used as a gauge. The garments are made to measure by changing the length of the sleeves or the body. Measurements are changed in steps of two centimetres and the maximum change is plus or minus eight centimetres. If a very tall and slim customer wants to buy a garment a narrow size, for example small is used as base and the body and sleeves are lengthened. Table 1 describes how the customers adjusted measurements of the garments.
Table 1  Average change of measurements

<table>
<thead>
<tr>
<th>Type of change</th>
<th>Average (cm)</th>
<th>Standard deviation (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only sleeve</td>
<td>1,8</td>
<td>2</td>
</tr>
<tr>
<td>Only body</td>
<td>-0,3</td>
<td>4,63</td>
</tr>
<tr>
<td>Both sleeve and body</td>
<td>Sleeves</td>
<td>Body</td>
</tr>
<tr>
<td></td>
<td>3,84</td>
<td>3,84</td>
</tr>
</tbody>
</table>

41 percent of the customers only changed one measurement. The customers who changed the length of the sleeves lengthened the sleeves with 1,8 centimetres on average, that is one length interval. Customers who only changed the body measurements decreased the length with 0,3 centimetres. 38 percent of the customer changed both body- and sleeve measurements. They lengthened the garments with almost two intervals on average, half of those customers had sizes that would not be covered the standard size, which basically means that no mass producer would produce garments that fit their size. 21 percent of the customers made no changes at all.

4.1 Production and order to delivery leadtimes
One of the original purposes of the Knit on Demand project was to test and evaluate the complete garment technology so that the appropriate machinery could be purchased. It was, however, considered too risky to invest in a complete garment machine for one research project, so the already existing fully fashioned and cut and sew machines were used. During the development of the garments it was considered whether to use only fully fashioned or only cut and sew. The technologies offered different set up and different placement of the customer order decoupling point (CODP) in the production line and Figure 5 illustrates this.

Figure 5  Production processes and the customer order decoupling point

Cut and sew has in theory the fastest order to delivery time, since panels can be knitted and kept in stock until a customer order arrives. Such set up would also create less dependency on available knitting capacity within the promised lead-time, since the fabric for the garment has already been produced. It is also flexible, since any shape can be cut from the panels. Cut and sew does, however, create more material waste compared to fully fashioned and complete garment since the panels are cut into pieces and the pieces of the garments have to be sewn together, which requires available sewing capacity.
Before a fully fashioned garment can be produced it is programmed in a computerised design system that is connected to the knitting machine. Fully fashioned is a little slower from order to delivery, since the garment pieces cannot be knitted until there is a customer order. The order to delivery lead-time is about one hour longer, so compared with the promised lead-time of three weeks, it is not much. But the problem is not lead-times in the knitting machine; it is that there has to be available knitting capacity within the promised lead-time. Fully fashioned (if correctly utilised) creates no waste of material, but the pieces have to be sewn together, which adds to the lead time.

6.1 Knit on Demand production process

The best logistical solution is not always chosen. In this project a trade off was made between flexibility and the look of the garment, especially the seams. The look of the garment was considered more important and fully fashioned garments have neater looking seams where the body of the garment meets the arms. Therefore, fully fashioned garments were used for most parts but cut and sew was used on the neck.

There are several decoupling points in the supply chain, but this paper focuses on the process from the customer order decoupling point (CODP) and downstream. Figure 6 illustrates the production Knit on Demand production process with lead times, set up times and standard allowed minutes (SAM). Standard allowed minutes is the time each operation is allowed to take, and it differs from the actual lead time depending on how much set up time a process is allowed to have.

Figure 6. Process steps with lead times, set up times and standard allowed minutes (SAM)

<table>
<thead>
<tr>
<th>Step</th>
<th>Lead Time (L/T)</th>
<th>Set Up Time (S/T)</th>
<th>SAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knitting</td>
<td>L/T = 33 min</td>
<td>S/T = 5 min</td>
<td>SAM = 69 min</td>
</tr>
<tr>
<td>Washing (rinse program)</td>
<td>L/T = 5 min</td>
<td>S/T = 3 min</td>
<td>SAM = 5,75 min</td>
</tr>
<tr>
<td>Tumble drying</td>
<td>L/T = 60 min</td>
<td></td>
<td>SAM = 2,875 min</td>
</tr>
<tr>
<td>Steam &amp; Press</td>
<td>L/T = 2,5 min</td>
<td></td>
<td>SAM = 22,5 min</td>
</tr>
<tr>
<td>Cutting</td>
<td>L/T = 5 min</td>
<td>S/T = 2,5 min</td>
<td>SAM = 3,85 min</td>
</tr>
<tr>
<td>Sewing</td>
<td>L/T = 15 min</td>
<td></td>
<td>SAM = 6,25 min</td>
</tr>
<tr>
<td>Finishing &amp; inspection</td>
<td>L/T = 3,5 min</td>
<td></td>
<td>SAM = 2,875 min</td>
</tr>
</tbody>
</table>

The total value adding time in the production process is 126 minutes. With set up times and waiting times the production lead time is 136,5 minutes. However, when the cost of the garment is calculated, the total time is calculated using the standard allowed minute. For example, in the knitting production step the allowance is 100 percent due to downtime, set up time and problems that might occur with each new garment. Using SAM, the total lead time equals 179,7 minutes.

Delivery time to stores in Stockholm or directly to the customer is one to two days. Before the customer picks up the garment at the retailer the labels are added and the customer is notified via phone or e-mail, the price for delivery is 70 SEK and is included in the retail price.

The total lead time from customer order to delivery varies from one to three weeks. The target is to reduce the throughput time in the factory to fewer than five days, decreasing the total lead time to one week. However, to reach that goal, the volume must increase to at least one garment per day. Then one knitting machine can be dedicated to the customised garments for one day. This procedure offers several benefits. The machine operator gets a sense of focus and learns the personality of the
particular knitting machine being used. Additionally, if a customer decides that the finished garment is not what was ordered, he or she, according to Swedish consumer laws (referens), is not allowed to return the the garment unless the customer can prove that the company has not produced according to the order specifications, such as the wrong colour of the yarn. In such cases the customer receives a new garment that meets his or her preferences.

6.3 Price and cost
One concern in the project was that customers would not be willing to pay the price for a garment, which retails between 1300 and 1600 SEK depending on model and add-ons. However, few of the interviewed customers were concerned about price. They accepted a higher price as long as they got their unique garment or a garment that fit well. The production cost is 265 SEK for a standard V-neck garment, about 60 SEK higher than for an equivalent standard garment; the wholesale price is 600 SEK; and the garment retails for 1400 SEK. Thus, the markup at the wholesaler is what can be expected for a fashion garment, around 2.5 times the wholesale price. The cost of delivery from the producer to the store is 50 SEK per garment with the Swedish post.

5 Discussion
The Knit on Demand concepts fits the description of collaborative customisation as described by Gilmore and Pine (1997). Customers are allowed to change both the appearance of the garment and functionality, in this case the size. Collaborative customisation requires a high level of customer integration; in this case that is the integration of the customer in the customisation process. Without that integration the concept would not function properly. Salvador et al. (2004) describes this type of customisation as hard customisation with demand for high responsiveness in the supply chain. The analysis of the customisation process showed that most customers made size adjustments to the garments, even though some of them small. This shows that there is a need for mass customised knitwear.

A combination of fully fashion and cut and sew knitting technologies offers the best balance between flexibility and economies of scale. Modularity is the key for successful mass customisation (Mikkola and Skjott-Larsen, 2004, Pine et al., 1993) and in this case all the garments build on the same base module that is adjusted according to the customer’s measurements. The platform design increases quality of the product, which has to be 100 percent. It is simply not affordable to produce faulty garment that has to be returned. The platform design together with a one-piece flow helps to increase quality. Even though the Knit on Demand production processes are not a picture perfect match to what Miltenburg (2000) describes as a one piece flow, it has similarities such as high flexibility and high product quality.

The manufacturing cost for the mass customised garments are 25 percent higher compared to an equivalent standard garment. Other authors such as Alvan and Aydin (2009) also concluded that productivity would decrease in mass customisation system. The higher manufacturing cost is because of the increased control in knitting operations.

In the perspective of lean and agile, the Knit on Demand supply chain can be described as a combination of the two. It is lean because the focus on only producing according to customer demand and thus reducing overproduction. The supply chain is also agile because it has a high level of customer integration, it requires a tight
collaboration between the actors in the supply chain and it would benefit from a higher degree of virtual integration. Therefore, it can be described as leagile (Mason-Jones et al., 2000b).

6 Conclusion
In this paper, the Knit on Demand supply chain was presented. From the one year of testing it a number of conclusions can be drawn, here are the most important ones related to supply chain management:

In the case of the Knit on Demand supply chain, it is justified to refer to profitable inefficiencies, that is inefficiencies needed to make money. Since it was a start up of a new business concept, it was not known what the best design, production or logistic solution was. However, the production method that the research team, production manager of the knitting company and retail owner chose offered the best trade off between design flexibility, manufacturability and aesthetics. Aesthetics received somewhat more attention than manufacturability and flexibility, since no unattractive garments would be sold. It has to be remembered that fashion always comes first.

The Knit on Demand supply chain could be considered as agile even though it does not have all the enablers that, according to the literature, constitute an agile supply chain. However, it is also a lean supply chain since it have several of the elements that is central in the lean philosophies. Therefore it can be described as a leagile supply chain that benefits from all the elements in both agility and lean philosophies.

It is about 25 percent more expensive to produce customised knitwear than standard knitwear. Since customised knitwear needs more attention in the knitting operation the company has to allocate double the time compared to a standard garment.
References


CSCMP (2011) 'Supply chain management definitions - Council of supply chain professionals'.


Paper VII

An explorative study on mass customisation of pants

Abstract: Jeans, chinos and slacks are usually made of stiff materials such as heavy cotton or wool weaves. The non-stretchy characteristics of these materials make the garments suitable for customisation. Fit is the main concern when somebody is purchasing a garment and it is also the main reason why consumers are dissatisfied with a garment. Fit is also the main reason why customers buy mass customised garments, followed by form and function. SOMconcept is a retailer and producer of mass customised garments such as jeans, chinos, slacks, suits and accessories. Customers who come to SOMconcept are either those who cannot find garments that fit them anywhere else, those who find excitement in designing their own garments, or both. This paper presents an explorative study on how customers purchase mass customised pants. The results show, inter alia, that jeans are more reduced in waist than chinos, that larger sizes generally are associated with larger increases in length and larger decreases in waist, and that blue jeans have more matching stitching thread colours than black jeans.

Keywords: Mass customisation; quantitative analysis; trousers; pants; made-to-measure;

1 Introduction

Mass customisation as a paradigm evolved from the mass production era because customers have started to ask for more diversity in product offerings and they are willing to pay the price for the convenience of having products customized for their needs (Franke and Schreier, 2008). The essence of mass customisation is to produce individualised products at near mass production efficiency (Pine, 1993). A lot of research has been done to define mass customisation and how it works (Da Silveira et al., 2001; Pine, 1993; Gilmore and Pine, 1997; Feitzinger and Lee, 1996; Pine et al., 1993). Research has also been conducted on what type of customers choose make their own design. Fiore et al. (2004) writes that customers who are fashion innovators are more likely to mass customise a fashion garment. A fashion innovator is a customer who spends more money and time on fashion than average in his or her social context (Goldsmith et al., 1999). Also, the more a customer can customise a garment, the more he or she is willing to pay for it compared to the off-the-shelf standard (Franke and Schreier, 2008). There are three reasons why customers choose to customise fashion garments. They are fit, form and function. A significant amount of jeans customers said that the fit did not meet their expectations on measurements such as waist line, inner leg, hip size etc. (Bickle et al., 1995). Usually customers with smaller sizes are more satisfied with the fit of their garments. One of the reasons customers may not be happy with the fit of garments is that the garments are fitted on the fashion company’s size model, usually one that the company thinks fit their clothes best in terms of proportions, contours, symmetry and posture (Kwong, 2004). Moreover, jeans are advertised on models and in environments that may increase the expectations of the jeans. Sometimes customers also blame
themselves and their personal physical flaws for not being able to fit into the expected size (Schofield and LaBat, 2005). In order to manage the fit problem, the fashion and textile industries have conducted numerous surveys in different countries, all with the aim of creating sizing systems that correspond to the anthropometrics of the people in their country or region. Since 1920, more than 50 large scale anthropometric studies ($n$ between 10,000 and 100,000) have been performed (Yu, 2004). Sizing systems are a set of size charts, each developed to fit one category of body types in the population (Schofield and LaBat, 2005). There are standard sizes to cover most body shapes; for example, Germany has eight different figure types for men—athletic, slim, normal, stocky, large, short stocky, large waist, and short large waist. Women’s body types are divided into nine figure types: average height, short or tall and in each group three hip types, slim, average and wide. Sizing systems vary from country to country and firm to firm. Therefore in 1968, Sweden took the first official initiative to create a standard ISO (International Standard Organisation) system for garments that was published in 1979 as ISO 8559 “Garment Construction and Anthropometric Surveys—Body Dimensions” (Yu, 2004). However, there are not enough customers in the most diverse body shapes to make it economically viable to produce garments for all of them, even if the standard sizes exist and it is possible to make patterns for those sizes.

The second reason why customers customise is form, or the design of the garment. For fashion garments, this reason why people choose to customise melts together with the third reason, function, since a garment’s function is to cover the wearer, keep the wearer warm or show to other people to which social context he or she belongs. Oliver et al. (1993) found that smaller men choose fashion fabrics to a greater extent than larger men who preferred more traditional styles when buying made-to-measure garments. Men of average length also tend to choose fashion fabrics more often than short or tall men. This could be because fashionable garments emphasize the body more than traditional garments and men of average weight and length are more comfortable with their size and therefore are more willing to take fashion risks. However, big and tall men are buyers of garments that do more than just fit their bodies. A growing number of big and tall men believe that clothing is an important tool in building a career, and those that actively engage in social lifestyle and cultural activities show higher interest in fashion, but cannot find apparel that fits their preferences since fashion companies traditionally cater to the average population. On average, big and tall men are more dissatisfied with the service at the retailer and especially with fit (Shim and Kotsiopulos, 1991).

2 Mass customised pants

Jeans and chinos are usually made of a heavy cotton weave that does not stretch very much, if any at all. The non-stretchiness of the denim material is one of the reasons why customers are not satisfied with the fit of jeans in particular (Bickle et al., 1995). However, such fabric characteristics open up for mass customised pants for customers that are a little longer, wider or that
do not fit into the most common sizes in some other way. Levi’s Strauss tried mass customised jeans in the mid-1990s with their “Personal Pair” customized jeans program for women, but decided to quit since the customers though of it as a nuisance to visit the Levi’s store every time they wanted to buy a new pair (Lee and Chen, 2000). This also happened before the Internet, which meant that the only convenient way of customising jeans was to visit the store. Landsend.com has offered customised jeans for some years and a few more are popping up; Tailorstore.com, which has been operating on the mass customization market since 2003, started to offer customized chinos in 2010. SOMconcept AB is a Swedish tailor of fashion garments that offers mass customised jeans, chinos, jackets, suits and accessories to customers who cannot find their fit and model preferences in traditional retail outlets. Some of them have never been able to wear a garment that fit them perfectly or fit their desired style since the fashion companies cannot find enough customers for economies of scale. The SOMconcept store is situated in a department store in Stockholm, which provides enough customers with the right fashion ethos to run a mass customisation business. In addition to the store they also have an online interface where customers can order customised jeans (Figure 1) and cater to those customers who do not have time to come to the store.

SOMconcept offers a wide range of customisation possibilities for pants. These can be divided into three categories: fit, colours and attachments.

Customers can choose between three different models of jeans, slim, classic and wide fit; two different models of chinos, slim and wide; and two different slack models, slim and wide. The customer is measured with measuring tape and the measurements are translated to the nearest standard size by the store staff. For jeans that is size 28 to 38 and for chinos and slacks 44, 46, 48, 50,
52, 54 and 56. Waist and length are the two measurement variables used. Customers can also make alterations on the model, if they would like a boot cut model or baggier pants, for example.

Customers can choose between several different fabric qualities, with or without stretch, contrast fabrics and different colours of thread and stitching. There are also contrasting fabrics for inner lining and pockets.

Customers can choose between different pockets and number of pockets on chinos and slacks, button or zip fly on both chinos and jeans, and bronze or silver button and studs.

2.1 Purpose of the paper

This paper presents the results of an explorative study on how customers purchase mass customised pants. The purpose is to explore the differences in customization between types of pants and associations between types of customization.

3 Method

The study can be seen as an experimental study with real customers as test subjects. A more conservative view is to regard it as a case study, since the representativeness is difficult to assess. A consecutive sample strategy was used. All customized pants ordered between 2006 and 2010 were included in the sample, i.e., from the time SOMconcept began to offer customized pants until the time the data collection was suspended in order to begin the analysis. In total, 494 customized pants were ordered during the period. For each garment, the customer filled out an order sheet in cooperation with the staff in the store. The sheet included customer demographics and similar data, information about the type, model, colour and size of the garment, information about individual adjustments to be made in length and waist and information about matching stitching thread colours. The study was based on the information on these 494 sheets.

Proper parametric methods, t-tests and ANOVA with post hoc testing with Dunnet’s T3 were used to compare means. Correlation between sizes and other variables was analysed with non-parametric methods since size is ordinal.
4 Results

Table 1 shows the distribution over different types of pants is displayed.

Table 1: Types of pants

<table>
<thead>
<tr>
<th>Type</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chinos slim</td>
<td>167</td>
</tr>
<tr>
<td>Chinos wide</td>
<td>1</td>
</tr>
<tr>
<td>Slacks slim</td>
<td>41</td>
</tr>
<tr>
<td>Slacks wide</td>
<td>1</td>
</tr>
<tr>
<td>Jeans classic</td>
<td>134</td>
</tr>
<tr>
<td>Jeans slim</td>
<td>127</td>
</tr>
<tr>
<td>Jeans straight leg</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>494</td>
</tr>
</tbody>
</table>

Table 2a shows the average adjustments in length for the different types of pants. All three types of pants are characterized by an average increase in length measurement. The differences seem rather small in relation to the standard deviations, but they were further analyzed with an ANOVA, which is displayed in Table 2b. As expected, the ANOVA did not reveal any significant differences in length adjustment between the types of pants.

Table 2a: Length adjustment, descriptive statistics

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Mean</th>
<th>Std.dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jeans</td>
<td>284</td>
<td>1.34</td>
<td>6.41</td>
</tr>
<tr>
<td>Chinos</td>
<td>168</td>
<td>0.85</td>
<td>6.27</td>
</tr>
<tr>
<td>Slacks</td>
<td>42</td>
<td>1.46</td>
<td>7.82</td>
</tr>
<tr>
<td>Total</td>
<td>494</td>
<td>1.18</td>
<td>6.49</td>
</tr>
</tbody>
</table>

Table 2b: Length adjustment, ANOVA

<table>
<thead>
<tr>
<th></th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between groups</td>
<td>28.956</td>
<td>2</td>
<td>14.478</td>
<td>.343</td>
<td>0.710</td>
</tr>
<tr>
<td>Within groups</td>
<td>20710.346</td>
<td>491</td>
<td>42.180</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>20739.302</td>
<td>493</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3a displays the average adjustments in waist for the different types of pants. All three types of pants are characterized by an average decrease in waist measurement. The differences were further analyzed with an ANOVA, which is displayed in Table 3b. The ANOVA was significant (p=0.005) and post hoc testing with Dunnet’s T3 showed that jeans and chinos on average have significantly different waist adjustments (p=0.004).

**Table 3a: Waist adjustment, descriptive statistics**

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Mean</th>
<th>Std.dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jeans</td>
<td>284</td>
<td>-0.78</td>
<td>1.99</td>
</tr>
<tr>
<td>Chinos</td>
<td>168</td>
<td>-0.17</td>
<td>1.91</td>
</tr>
<tr>
<td>Slacks</td>
<td>42</td>
<td>-0.69</td>
<td>1.44</td>
</tr>
<tr>
<td>Total</td>
<td>494</td>
<td>-0.56</td>
<td>1.94</td>
</tr>
</tbody>
</table>

**Table 3b: Waist adjustment, ANOVA**

<table>
<thead>
<tr>
<th></th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between groups</td>
<td>39.503</td>
<td>2</td>
<td>19.751</td>
<td>5.346</td>
<td>0.005</td>
</tr>
<tr>
<td>Within groups</td>
<td>1814.108</td>
<td>491</td>
<td>3.695</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1853.611</td>
<td>493</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4a shows the average number of matching stitching thread colours for the different types of pants. It is easy to see that jeans on average have more matching stitching thread colours than both chinos and slacks. An ANOVA (see Table 4b) shows that the differences are significant (p<0.001). Dunnet’s T3 confirms that jeans on average have a significantly different number of matching stitching thread colours than both chinos and slacks (p<0.001 in both cases).

**Table 4a: Matching stitching thread colours, descriptive statistics**

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Mean</th>
<th>Std.dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jeans</td>
<td>284</td>
<td>1.31</td>
<td>0.67</td>
</tr>
<tr>
<td>Chinos</td>
<td>167</td>
<td>0.78</td>
<td>0.60</td>
</tr>
<tr>
<td>Slacks</td>
<td>39</td>
<td>0.72</td>
<td>0.69</td>
</tr>
<tr>
<td>Total</td>
<td>490</td>
<td>1.08</td>
<td>0.70</td>
</tr>
</tbody>
</table>
Table 4b: Matching stitching thread colours, ANOVA

<table>
<thead>
<tr>
<th></th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between groups</td>
<td>34.249</td>
<td>2</td>
<td>17.125</td>
<td>40.784</td>
<td>0.000</td>
</tr>
<tr>
<td>Within groups</td>
<td>204.486</td>
<td>487</td>
<td>.420</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>238.735</td>
<td>489</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The correlations between the size of the garment and the size of the adjustments in length and waist were analyzed with Spearman’s correlation coefficient for all three types of pants. Table 5 shows the results. As we can see, larger sizes are significantly associated with larger increases in length for all types of pants. For chinos and slacks, larger sizes are significantly associated with larger decreases in waist. However, for jeans, the association between size and waist adjustment is very weak and far from significant.

Table 5: Correlations between size and adjustments

<table>
<thead>
<tr>
<th></th>
<th>Waist adjustment</th>
<th>Length adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size jeans</td>
<td>-0.033</td>
<td>0.299</td>
</tr>
<tr>
<td>Size chinos</td>
<td>-0.369</td>
<td>0.274</td>
</tr>
<tr>
<td>Size slacks</td>
<td>-0.468</td>
<td>0.390</td>
</tr>
</tbody>
</table>

Note: ‘*’ corresponds with a p-value below 0.05 and ‘**’ with a p-value below 0.01.

As we saw in table 1, the slim style is essentially the only type of garment demanded by customers interested in chinos and/or slacks. For jeans, however, there are demands for all three types of garments. Therefore, jeans have to be analyzed in more detail. As shown in Table 6, the dominating colours for jeans are blue and black. The “other” category includes all other colours such as grey, khaki, brown, light blue, and marine blue, for which only a few jeans were ordered. Hence, with respect to colour, we should primarily contrast the characteristics for black and blue jeans.

Table 6: Jeans colours

<table>
<thead>
<tr>
<th>Colour</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>84</td>
</tr>
<tr>
<td>Blue</td>
<td>124</td>
</tr>
<tr>
<td>Other</td>
<td>76</td>
</tr>
</tbody>
</table>

In Table 7, the average length and waist adjustments as well as the average number of matching stitching thread colours are contrasted for black and blue
jeans. The observed differences in length and waist adjustment are not significant (p>0.25 in both cases), but the difference in the average number of matching stitching thread colours is significant (t=−2.267, p=0.024). Therefore, customers who order blue jeans want more matching stitching thread colours than the customers who order black jeans.

Table 7: Black and blue jeans, descriptive statistics

<table>
<thead>
<tr>
<th>Colour</th>
<th>n</th>
<th>Length adjustment</th>
<th>Waist adjustment</th>
<th>Matching stitching thread colours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Std.dev.</td>
<td>Mean</td>
</tr>
<tr>
<td>Black</td>
<td>84</td>
<td>2.11</td>
<td>7.02</td>
<td>-0.84</td>
</tr>
<tr>
<td>Blue</td>
<td>124</td>
<td>1.03</td>
<td>6.45</td>
<td>-0.72</td>
</tr>
</tbody>
</table>

As we saw in Table 1, jeans are offered in three different models, classic, slim and straight leg. Table 8a demonstrates the average length and waist adjustments and the average number of matching stitching thread colours for the three models. As we can see, the slim model is on average not increased in length, in contrast to the other two models. The classic model is in between the other two with respect to average decrease in waist measurement, and all models have a similar average number of matching stitching thread colours.

Table 8a: Classic, slim and straight leg jeans, descriptive statistics

<table>
<thead>
<tr>
<th>Type</th>
<th>N</th>
<th>Length adjustment</th>
<th>Waist adjustment</th>
<th>Matching stitching thread colours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Std.dev.</td>
<td>Mean</td>
</tr>
<tr>
<td>Classic</td>
<td>134</td>
<td>2.61</td>
<td>7.05</td>
<td>-0.60</td>
</tr>
<tr>
<td>Slim</td>
<td>127</td>
<td>-0.04</td>
<td>5.57</td>
<td>-1.10</td>
</tr>
<tr>
<td>Straight leg</td>
<td>23</td>
<td>1.63</td>
<td>5.46</td>
<td>-0.02</td>
</tr>
</tbody>
</table>

The differences were further analyzed with ANOVAs (Table 8b). The ANOVA for length adjustment was significant (p=0.003) and post hoc testing with Dunnet’s T3 showed that classic and slim have significantly different length adjustments on average (p=0.003). The ANOVA for waist adjustment was also significant (p=0.021) and post hoc testing with Dunnet’s T3 showed that slim and straight leg on average have significantly different waist adjustments (p=0.009).
Table 8b: Classic, slim and straight leg jeans, ANOVA

<table>
<thead>
<tr>
<th></th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length adjustment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between groups</td>
<td>459.212</td>
<td>2</td>
<td>229.606</td>
<td>5.772</td>
<td>0.003</td>
</tr>
<tr>
<td>Within groups</td>
<td>11177.658</td>
<td>281</td>
<td>39.778</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>11636.870</td>
<td>283</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Waist adjustment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between groups</td>
<td>30.389</td>
<td>2</td>
<td>15.194</td>
<td>3.914</td>
<td>0.021</td>
</tr>
<tr>
<td>Within groups</td>
<td>1090.794</td>
<td>281</td>
<td>3.882</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1121.182</td>
<td>283</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Matching stitching</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between groups</td>
<td>0.141</td>
<td>2</td>
<td>0.071</td>
<td>0.157</td>
<td>0.855</td>
</tr>
<tr>
<td>Within groups</td>
<td>126.207</td>
<td>281</td>
<td>0.449</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>126.349</td>
<td>283</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5 Analysis and discussion

The purpose is to explore differences in customization between types of pants and associations between types of customization. There are two types of adjustments—size and design. The results can be used to further improve the selection of colours, fabrics and adjustments.

5.1 Size adjustments

Customers with larger sizes tend to do more size adjustments on their pants than customers with smaller sizes, both on chinos and jeans. This result supports Kwong’s findings (2004) that customers with larger sizes are less satisfied with the fit of pants than customers with smaller sizes. The size adjustments are mostly toward longer and thinner silhouettes, which may suggest that thin, narrow and tall sizes are difficult to find in regular outlets. Jeans customers decrease the waist measurement more than customers who purchase chinos; slim fit are, on average, decreased more in waistline than classic fit. Of the jeans customers, those who purchased slim fit jeans decreased the waistline more than those who purchased classic fit, who lengthen the jeans more. Chinos customers with larger sizes tend to decrease the waist measurement more than customers with smaller sizes and they also lengthen their pants more than customers with smaller sizes. Chinos customers purchase almost exclusively slim fit models. Jeans customers with larger sizes tend to lengthen the garments more than customers with smaller sizes. Also, on average jeans with classic fit are lengthened more than slim fit jeans. This suggests that taller men prefer classic jeans models. Large men who purchase made-to-measure garments tend to be more restrictive than smaller men and make design choices that do not emphasize their bodies (Oliver et al., 1993). Tall men prefer pants that do not emphasize their long legs and therefore prefer a more classic fit over the slim fit models. However, chinos customers purchase almost exclusively slim fit and there were no
difference in length adjustment between chinos, jeans and slacks.

5.2 Design adjustments
Customers do more adjustments of colours on jeans stitching than on chinos, and customers who purchase blue jeans tend to use more colours on the stitching than customers who purchase black jeans.

5.3 Practical implications
When further developing the collection of mass customisable garments, explorative studies like this have great value. Usually when a garment is ordered, the fabric is cut from the roll (which is a time consuming process), the pattern is laid on the fabric and matched against the direction of the weave and then cut. By using these results it is possible to forecast the number of trousers in each colour and standard module and have them ready for sewing. This moves the decoupling point further downstream closer to the customer and saves valuable time in the order fulfilment process. For example, the results showed that customers lengthen their pants rather then shorten them; therefore modules with option on longer legs could help to shorten lead times. Design wise, the results help to develop the selection of colours on fabrics and threads. Since customers who purchase blue jeans tend to choose more colours on stitching, that range of options could be further developed.

Generalisation of results
Since this is a case study on one company, the generalizability of the results can be discussed. However, the study is conducted on real customers in a real environment where the actual customers are studied. Since the actual customer behaviour is studied, the results are more generalizable than if the study would have been performed using a survey or in a laboratory environment. The study includes every customer of mass customised jeans from 2006 to 2010.

6 Conclusion
The results show, inter alia, that jeans are more reduced in waist than chinos, that larger sizes generally are associated with larger increases in length and larger decreases in waist, and that blue jeans have more matching stitching thread colours than black jeans. The results are interesting since there are few studies on how customers purchase customized pants. Moreover, the results are applicable to the further development of SOMconcept’s range of customisation options; for example, modules of pants could be prepared in advance to shorten order fulfillment lead times.

7 Further research
This paper presents a explorative study on how customers choose to design their customised pants and how the results can be used to improve the offerings for customers. The paper does not present why customers choose to customize their pants. Therefore, as the next step the data could be compared
with sizing systems to analyse how much SOMconcept customers differ from the average population. Moreover, interviews should be performed with the customers to learn why they choose to purchase mass customised pants. Not all customers need customised pants because they do not find the right size at the prêt à porter retailers.

References


