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Joel Peterson

Customisation of Fashion Products Using Complete Garment Technology

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ABSTRACT

Complete garment knitting technology is a method of producing knitted products, generally fashion garments, ready-made directly in the knitting machine without additional operations such as cutting and sewing. This makes it possible to manufacture a knitted fashion garment with fewer processes then with conventional production methods. In the fashion business customer demand is always changing due to fashion trends, so to be able to manufacture and deliver products rapidly is important. Mass customisation is a customer co-design process of products and services that tries to meets the needs of an individual customer's demand for certain product features. In the fashion business this means that the customer can order a garment with a customised style, colour, size, and other personal preferences.

The principal objective of this dissertation was to examine if and how complete garment technology can be applied to the customisation of knitted fashion products. It was pursued through several independent studies in knitting technology, mass customisation, and fashion logistics against a theoretical frame of reference in these areas. The papers in this thesis present various examples of how knitted fashion garments can be customised and integrated into fashion retailing concepts.

The starting point of the research was the Knit-on-Demand research project conducted at the Swedish School of Textiles in collaboration with a knitting manufacturing and retailing company. The aim was to develop a shop concept built on the complete garment technology where a garment could be customised, produced, and delivered as quickly as possible. This initial idea failed due to the expense of investing in complete garment knitting technology, and so other avenues of research had to be found. The Knit-on-Demand project continued, using a business model similar to the complete garment concept but with the retail store and the production unit situated in different locations.

The overall research question addressed in this thesis is: *How can complete garment knitting technology be applied in a retail concept for customised garments?* This question is then divided in two problems: *What are the fashion logistics effects of combining complete garment technology and mass customisation? How does the co-design process function in the customisation of knitted fashion garments?*

The following is a qualitative study based on five research articles applying different research methodologies: case studies, simulations, and interviews. The empirical context is the area of mass customisation of fashion products and knitting technology, more specifically called complete garment knitting production technology. No prior studies describing mass customisation of complete garment knitting technology in combination with fashion logistics were found in the literature.

The main contribution of this study is the demonstration that complete garment knitting technology can be applied in the customisation of fashion products. It also illustrates the importance of the co-design process between the company and the customer through which a knitted garment can be customised, produced, and delivered to the customer in three to five hours. The process of co-design and manufacture of a customised complete fashion product is examined, and the advantages and disadvantages associated with customisation of knitted garments are identified and described.

PREFACE

The work presented in the thesis was carried out at the University of Borås, Swedish School of Textiles, and the Tampere University of Technology (TUT), Department of Materials Science. The Swedish School of Textiles has generously provided me with financial support for the preparation and completion of the thesis, without which it might never have been done. My special thanks to Kenneth Tingsvik who convinced me to study and launch this research in the first place.

I wish to thank Professor Heikki Mattila for kindly making it possible for me to undertake research studies at Tampere University of Technology and who, as my supervisor, guided and supported me from beginning to end. I also wish to express my appreciation to my supervisors Jan Carlsson and Professor Håkan Torstensson for their oversight and assistance during the whole PhD process.

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I wish to thank my father Stig, who died before my studies were finished, my mother Stina, and my sister Anna for their love and support. Finally, I would like to thank my wife Carina, and my children Fabian, Albin, Eskil, and Filippa for their love, encouragement, and patience throughout this process.

Sätila, September 2012
Joel Peterson

CONTENTS

LIST OF PUBLICATIONS

This dissertation is based on the following peer-reviewed publications (referred to in the text by their numbers). The articles are reprinted with the permission of the copyright holders.

1. Peterson, J. and Ekwall, D. (2007). "Production and business methods in the integral knitting supply chain." *Autex Research Journal*, Vol. 8, No. 4, 264-274.

2. Peterson, J., Larsson, J., Carlsson, J., & Andersson, P. (2008). "Knit-on-Demand: Development and simulation of a production and shop model for customised knitted garments." *International Journal of Fashion Design, Technology and Education*, Vol. 1, No. 2, 89-99.

3. Peterson, J. & Mattila H. (2010). "Mass customising of knitted fashion garments: Factory Boutique Shima – a case study." *International Journal of Mass Customisation*, Vol. 3, No. 3, 247-258.

4. Peterson, J., Larsson, J., Mujanovic, M., & Mattila, H. (2011). "Mass customisation of flat knitted fashion products: Simulation of the co-design process." *Autex Research Journal*, Vol. 11, No. 1, 6-13.

5. Larsson, J., Peterson, J., & Mattila, H. (2012). "The Knit on Demand supply chain." *Autex Research Journal*, Vol. 12, No. 3, xx-xx. (accepted for publication)

AUTHOR'S CONTRIBUTION

Article 1:
Joel Peterson wrote a substantial part of the article and is the corresponding author. The co-author, Daniel Ekwall, provided input in the methodology and contributed his expertise in the field of logistics.

Article 2:
Joel Peterson wrote the article and is the corresponding author. The co-authors provided input from their fields of expertise and commented on the text. Peter Andersson carried out the simulation program employed. Jan Carlsson contributed input about the Knit-on-Demand concept. Jonas Larsson assisted with his knowledge of logistics.

Article 3:
Joel Peterson wrote the article and is the corresponding author. The co-author, Heikki Mattila, provided input from his field of expertise in fashion logistics and commented on the text.

Article 4:
Joel Peterson wrote the article and is the corresponding author. The co-authors provided input from their fields of expertise and commented on the text: Jonas Larsson, mass customisation, Heikki Mattila, fashion logistics, and Malik Mujanovic, simulation program and computer simulation.

Article 5:
Jonas Larsson wrote the article and Joel Peterson participated as co-author and provided input from his field of expertise in knitting technology and production. Heikki Mattila, provided input from his field of expertise in fashion logistics and commented on the text.

LIST OF TABLES AND FIGURES

1 INTRODUCTION

This dissertation is the report of a study in the area of knitting technology and mass customisation (MC). It was based primarily upon a research project “Knit-on-Demand” at the Swedish School of Textiles in Borås in collaboration with a knitting manufacturing and retailing company. The aim was to study if it was possible to combine complete garment knitting technology with the concept of MC. This first chapter of the dissertation presents the background of the research, specifies the problem and the research questions of the study, and presents an overview of the methodology used. The chapter concludes with an outline of the structure and scope of the study.

1.1 Background

Humans have made clothing for thousands of years to protect their bodies against weather, wind, and other climatic conditions, especially in northern Europe. Garments were first constructed of animal skins and furs. Then, gradually, people turned to textiles of various kinds. Clothing was mostly made by weaving and knitting, originally by hand using very simple tools. These skills go far back in time. In Sweden as in many other countries the living conditions during the 18th and the 19th century were not easy and most of the people were farmers and had to live on what the farm could produce during spring and summer in order to survive the long, cold winter months. Many without their own land, crofters and other poor people ran out of food during the winter and were forced by hunger to go around to the farms to beg for something to keep them alive. In such an environment, where food and wood were grown locally, textiles and clothes were also made on the farm to satisfy basic needs. It was a common practice to weave and knit what was required. Through the millennia, people have been accustomed to producing clothing for their own needs. Garments have been made by handicraft using weaving, knitting, and sewing, with design and size often adapted to the user of the actual product. With this manufacturing method there was no over-production. Everything was produced for immediate need, and the garment fit the wearer. At this time, textile fabrics for clothing were relatively expensive and people commonly wove and knit their own. The raw materials were often wool and linen from the local area. The sheep were shorn and wool carded and spun into yarn on a wooden spinning wheel. The yarn was then used for weaving or knitting and products were made by hand with knitting needles. Caps, gloves, sweaters, and socks were produced this way.

The first knitting machine was invented in England in 1589 and made it possible to produce knitted products quickly and efficiently (Grass & Grass, 1967:59). In the eighteenth century a series of inventions appeared that enabled the industrial revolution that followed. This revolution, with its mechanisation of weaving and knitting, reached Sweden in the beginning of the 19^{th} century, and industries appeared mainly in and around Gothenburg and Sjuhäradsbygden, with Borås as their centre (Johansson, 2003:7).

The steam engine, weaving loom, and the first spinning machine or spinning jenny were among the developments that laid the foundation for the large textile industry that grew over the next 150 years (Johansson, 2003:23). These machines were initially driven by steam, but when electrification arose in the 1880s, this new force made its entry into the industries that produced textiles and garments.

The term *mass production* was first introduced in 1920s and is often associated with the factories of automobile manufacturer Henry Ford (Hounshell, 1984:1). Assemblies of electric-motor-powered moving conveyor belts moved partially completed products to workers, who performed simple repetitive tasks. Since then, almost all manufacturing of textiles and garments world-wide has taken place in factories using the industrial concept of mass production. For a long time textiles continued to be produced locally in Europe and elsewhere. In the 1960s labour costs increased in Sweden and in other countries of Western Europe, and so a great amount of domestic textile and garment production moved overseas, where manufacturing was cheaper (Segerblom, 1983:68).

To take advantage of low labour costs, a significant part of the Swedish clothing industry moved to Finland and Portugal in the 1960s, when salary levels were too high in Sweden. (Gustafsson, 1983:157-169). This trend continued with countries like Poland in the 1980s and the Baltic States in the 1990s. Trade with countries in Asia increased every year. Hong Kong, India, and Bangladesh became producers for European clothing companies, and this trend has since then continued with accelerating speed. The disadvantage with production in Asia is that orders have to be sent in months ahead of retail marketing campaigns. Transportation is also a time and cost factor due to the distance between Asia and Europe. Another problem is that orders must be placed so far ahead of season that when the garments finally arrive they may be out of fashion and must be sold at a reduced price. In the fashion business demand changes rapidly, and having a short time to market is vital if a company is to remain competitive. Production and logistics systems are needed that can put merchandise on the shelf to fulfil customer's desires at exactly the right time. The supply chain needs to be time-based, customer-oriented, and agile in response to changes in demand (Hoover et al., 2001:10).

A study of Finnish retailing companies' shows that the financial performance of traditional retailers with up-front buying is far poorer compared to retailers with in-season replenishment purchasing. (Mattila et al., 2002:350). Time is an important factor from *demand* to *fulfilment,* that is, from the moment customer request is identified until the customer buys the product. Another problem with textiles and apparel in the marketplace in Asia are environmental concerns with long distances and expensive shipping. Most of the cargo is shipped by sea, but air freight may be used when time is pressing and goods must reach the market quickly.

In 1987 Stan Davis, a visionary business thinker and consultant coined the term *mass customisation* for the first time. He described it as a system in which "the same large number of customers can be reached, as in mass markets of the industrial economy, but simultaneously can be treated individually, as in the era of customised markets in pre-industrial economies" (Davis, 1987:177). This was developed further by Pine (1993:44), who defined it as a concept that provides such variety and individual customisation that almost everyone can find what they want at prices comparable to mass-produced products.

MC involves all aspects of development, manufacturing, sales, and delivery of the product (Kay, 1993:15; da Silveira, Borenstein & Fogliatto, 2001:2). It is a concept that comprises the whole chain from the designer's sketch to the final product received by the customer.

MC allows buyers to modify products according to their taste and requirements. It exists today in a variety of areas including automobiles, furniture, food, and clothing. One advantage for the retailer is that the product can typically be sold before the manufacturing takes place. Since the customer has already purchased the product, the risk for unsold goods is lower. Customers are not always satisfied with the products they have customised and bought. For such cases it is important to have a return policy which allows returning with full refund. (Lee & Kunz et al., 2002:140).

The production of knitted fashion products has developed considerably since the 1970s due to improvements in electronics and computer engineering (Spencer, 2001:134). Two stages preceded complete garment technology. *Cut & sew* is a common method of making flat knitted garments (Choi, 2006:18). Rectangular panels for the front, back, and sleeves are knitted, then cut into shape, and finally joined together by the sewing process. *Fully-fashioned* or *shaped knitting* is a method of production in which the front, back, and sleeves are knitted in approximately the right shape directly in the knitting machine, but some additional cutting may be needed (Choi, 2006:18-21). After the knitting process, the parts are sewn together to form a garment.

Complete garment technology (*seamless garment technology*) was introduced on V-bed flat knitting machines in 1995, having evolved from developments in the 1980s. V-bed machines have two needle beds, in a position of an inverted V and equipped with needles (Spencer, 2001:207). Since then, the technology has been considered an innovative process and is steadily increasing in use around the world (Choi & Powell, 2005:1). In this type of production, the entire garment is ready-made directly in the flat knitting machine. The different parts of the garment are produced in the right shape and knitted together with the trimmings, pockets, and other accessories. This technology makes it possible to eliminate cutting and sewing operations and produce 'on-demand' knitting, which can shorten lead times considerably (Legner, 2003: 240).

While MC may not replace mass production of clothing, it may be a solution for certain products and niche markets. In some ways the MC of clothing may be seen as a step back in time. We are reminded of the crafts era, when clothing was made to order as needed and produced near-by. Now this is being done again, but with modern technology—a return to clothing designed and manufactured in collaboration with the wearer. Here complete garment technology opens up new perspectives with its reduction of processes that allow a rapid response to customer demand, while the possibility of MC serves each customer individually. Fashion logistics, MC, and complete garment technology form an effective partnership. These three concepts are the focus of this study. They are relatively new and, while they have been considered separately, they have rarely or not at all been examined in combination.

1.2 Knit-on-Demand: research case

Knit-on-Demand is a research project launched in 2006 at the Swedish School of Textiles, University of Borås, in collaboration with a Swedish knitwear production and retailing company, Ivanhoe AB. The initial idea was to build a design, production, and shop model for the concept to demonstrate how complete garment knitting technology could be used for customised products. A business model was planned with production equipment located in a store where customers could be involved in the design process and customised garments could be quickly made to fulfil actual demand.

As described by one of the original members of the Knit-on-Demand team, The purpose of the project "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" (Larsson, 2011:12). Figure 1.1 shows the set up of the store.

When a customer finalised a garment with the guidance of a design technician, it was to be manufactured as quickly as possible on a complete garment knitting machine in the store or at a near-by site. Delivery was planned to take place in three hours. Meanwhile, customers could shop at other stores in the area or have something to eat. The concept proved infeasible because of the investment needed for a complete garment knitting machine and CAD equipment (Larsson, 2011:47). The project was modified and the shop was relocated in a retailer's store, SOMConcept AB, selling tailored fashions in Stockholm. The store also sold other customisable products, such as belts, jackets, suits, and pants, and management wanted to extend the assortment with knitwear. The co-design stage was a manual process in the store in Stockholm with interaction between shop personnel and the customer, but no design system or configurator was involved as originally planned. The store also had no on-site knitting machine, but sent its orders to Ivanhoe AB, a manufacturer located in Gällstad, 380 kilometres from Stockholm. The garments were not produced with complete garment technology. Order fulfilment lead time was much longer than the three hours envisioned and turned out to be one to three weeks.

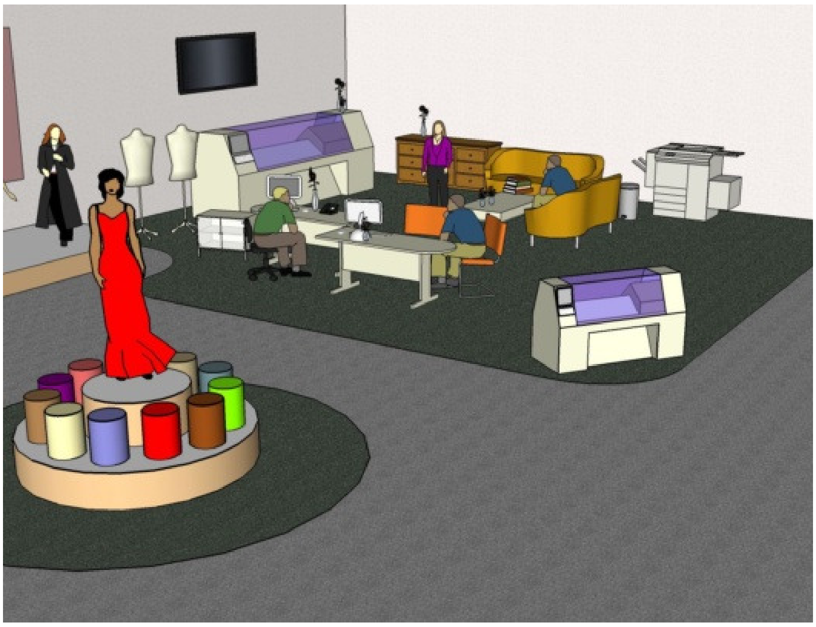

Figure 1.1. Initial model of Knit-on-Demand store (Larsson, 2011:12).

Three researchers involved in the Knit-on-Demand project each took on different tasks.

- Jonas Larsson was responsible for the development of the concept and logistics. His thesis, "Mass Customised Fashion," focused on the supply chain part of the Knit-on-Demand concept (Larsson, 2011).

- Pia Mouwitz, the second researcher, was responsible for the design of the garments.

- Joel Peterson, author of this thesis, took the lead with regard to knitting technology development.

When the initial research project was modified during 2007 and it was clear that no complete garment machine could be purchased, other areas incorporating this technology were studied (Larsson, 2011:47).

1.3 Objectives and research questions

The principal objective of the present study is to examine the use of complete garment flat knitting technology for the production of customised knitted garments. It is hoped that this will contribute to the industry discussion of how complete garment knitting technology can be applied in the MC of fashion products. This thesis attempts to bridge the gap between complete garment knitting technology, fashion logistics, and MC. It poses the following overall research objective: *How can complete garment knitting technology be applied in a retail concept for customised garments?* The answer is pursued in five articles containing literature reviews, simulations, and case studies.

Research Question One (RQ1): *What are the fashion logistic effects of combining complete garment technology and MC?*

Over the last 50 years the mass production of textiles and fashion garments has largely moved from Europe to countries in Asia and North Africa because of low labour costs (Mattila, 1999:87). One disadvantage this brings is the long lead times for design, product development, manufacturing, and delivery. By contrast, MC, a concept in which a garment is designed and sold to a consumer before it is manufactured, opens up new possibilities from a fashion logistics perspective. It permits a short lead time from the moment an order is placed to the delivery of the product to the customer. Such expeditious fulfilment increases the likelihood that a garment will be sold at full price ("sell-through"). RQ1 comprises the fashion logistics factors a) demand fulfilment time, b) sell-through, c) lost sales, and d) stock turn.

Research Question Two (RQ2): *How does the co-design process function in the customisation of knitted fashion garments?*

Co-design is a collaborative process between the customer, the retailer, and the manufacturer by which a product is customised to fulfil the customer's requirements. According to Franke and Piller (2003:581), the success of a co-design system is defined by its technological aspects (generally software-based) and how well it works in the sales environment.

RQ2 analyses how manual and digital co-design processes operate in combination with complete garment technology. The Knit-on-Demand research project and the five articles supporting this thesis may be summarised as follows:

Article 1 (Peterson and Ekwall 2007) describes how complete garment knitting production technology may be implemented in a rapid fashion logistics system. The advantages of complete garment production are compared from a technical point of view with traditional production methods such as "cut & sew" and "fully-fashioned". The article also considers ways to reduce production time in the supply chain by eliminating processes and non-value added time between operations.

Article 2 (Peterson, Larsson, Carlsson and Andersson 2008) presents a design, production, and shop model for the Knit-on-Demand concept, and shows how complete garment knitting technology can be used in retailing customised products. A business model with production equipment located in the retail store and a lead time simulation of design and manufacturing processes on-site is performed using AutoMod software, showing that the customer could have a self-designed garment in three to five hours.

Article 3 (Peterson and Mattila 2010) demonstrates how complete garment knitting technology can be used for MC of knitted products through a case study of Factory Boutique Shima in Japan, a shop for the on-demand retailing and production of customised knitted garments where customers may co-design a garment to their taste by deciding on style, material, pattern, and colour.

Article 4 (Peterson, Larsson, Mujanovic and Mattila 2011) focuses on the co-design process for customised knitted fashion products by comparing a manual process and one using a computer software configuration tool, Ordermade WholeGarment. A computer simulation was used to analyse the lead times and efficiency of each concept.

Article 5 (Larsson, Peterson and Mattila 2012) analyses the Knit-on-Demand research project, a production concept for knitted fashion products that addressed the demand for expeditiously supplying clients with custom-made garments. MC was used in combination with knitting technology to solve the logistical challenges for the companies involved, such as the one-piece flow of customised products through the supply chain in a mass production environment.

1.4 Structure and scope of the study

This thesis is structured as shown in Figure 1.2.

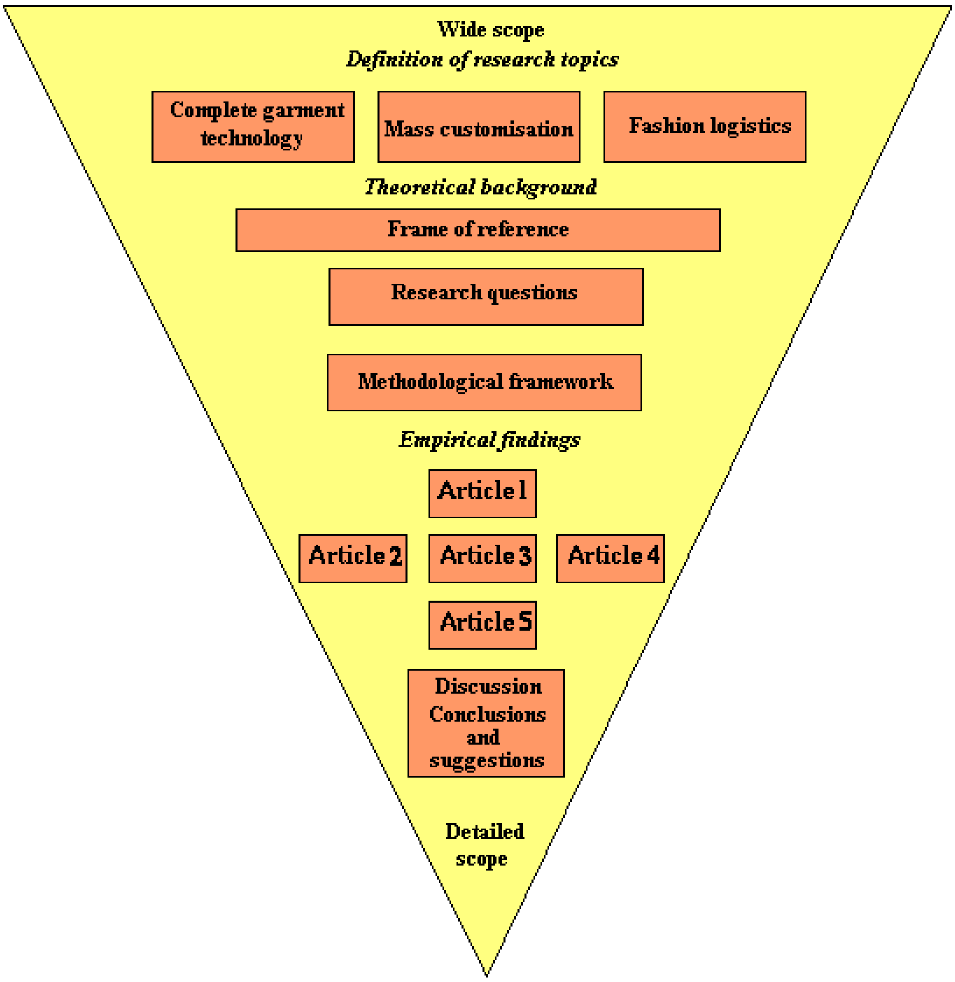

Figure 1.2. Structure of the dissertation with reference to Chapters 1 to 6 and the independently published articles [1–5].

Chapter 1 provides background and presents the study's objectives and research questions.

Chapter 2 lays out the frames of reference regarding knitting technology, fashion logistics, and MC, in addition to giving definitions and parameters for textile techniques and machinery. It also describes the development of complete garment flat knitting technology.

Chapter 3 presents the methodological framework, research procedure, and where a research gap exists with regard to the research questions. The final section of the chapter discusses the methodology used in data gathering and analysis.

Chapter 4 summarises the five articles supporting the present study. It shows how the articles are related to one another and to this thesis.

Chapter 5 analyses and discusses the results of the research presented in terms of its practical and theoretical implications. The relevance, validity, and reliability of the research presented are also reviewed.

Chapter 6 draws conclusions and suggests areas for further research.

2 FRAME OF REFERENCE

The production of customised knitted garments depends on theoretical frames of reference from three perspectives: fashion logistics, mass customisation (MC), and knitting technology.

2.1 Fashion Logistics

The concept of fashion logistics, in addition to what its name implies, embraces supply chain management (SCM) and quick response. It has become an essential component of customised knitting.

2.1.1 Fashion and apparel

Fashion is a broad term that covers a wide range of goods and services. It can be applied to products or trends like food, cars, perfumes and other beauty products, music, lifestyles, as well as textiles like curtains, upholstery fabrics, table linens, and wallpaper. The term *apparel* comes from the French word for clothing and is commonly used in the US to describe the garment industry (Hines & Bruce, 2007:2). The fashion industry is generally synonymous with textile and clothing (apparel), which is how the term fashion will be used here.

2.1.2 Supply chain management (SCM)

Logistics refers often to as the flow of raw materials, products, money, and information in a chain of supply activities that brings a product on the market. It often involves the handling of data, material, transportation, inventory planning, packaging, and display of the product.

Council of Supply Chain Management Professionals (CSCMP), a world wide association of professionals in supply chain management defines logistics as follows:

"*The process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods including services, and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements. This definition includes inbound, outbound, internal, and external movements*" (CSCMP, 2010).

Supply chain management denotes the coordination of all the activities necessary to bring a product to market, including procuring raw materials, producing goods, transporting and distributing the goods, and overseeing the selling process (Abend, 1998:48). CSCMP defines the term as follows:

"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" (CSCMP, 2010).

SCM is now seen as a broader concept of manufacturing and retailing than earlier views that limited it to individual companies. In a chain for textiles and apparel, all parts must be synchronised and able to adapt to demands on the market. This is especially crucial for the types of products that fashion represents (Bruce & Daly et al., 2004:152).

Nowadays, SCM focuses on relationships between those in the supply chain (Stuart, 1997:224; Dossenbach, 1999; Bruce & Daly et al., 2004:153). Retailers collect detailed point-of-sales information that reflects real-time demand for goods by consumers. Through computer systems, they then share this information with suppliers who, in turn, can ship orders within days to automated distribution centres (Abernathy et al., 1999:1). SCM takes a wide view of configurations, which Gattorna (2010:4) defines as "any combination of processes, functions, activities, relationships and pathways along which products, services, information and financial transactions move in and between enterprises, in both directions." Gattorna stresses the importance of having the definition embrace everyone in the company for SCM to work.

2.1.3 Definitions and success factors in fashion logistics

The textile and fashion industry is often characterised by its many SKUs (stock keeping units) and the uncertainty of its market. A SKU is a unique product code for each item offered for sale to a customer. The fashion industry is forced to deal with a large number of SKUs because a garment or style is available in many colours and sizes. A knitted sweater, for example, may be offered in five colours and four sizes, resulting in 20 SKUs for a single garment. Since a department store is divided into menswear, womenswear, and children's clothing, and each of these are subdivided into product categories such as trousers, underwear, etc., a significant number of SKUs are required to identify a store's inventory (Abernathy et al., 1999:45).

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Logistics for fashion products are also marked by a climate of uncertainty due to rapid changes in trends and fluctuating customer demand. For this reason, it can be an advantage to bring products to market as quickly as possible or retailers may be left holding unsalable merchandise because items have gone out of fashion.

The rent for an upscale clothing store in a good location is very high, so it is essential to carry the correct level of inventory. An example of this is the company Hennes & Mauritz who closed its main store in central Hong Kong in 2012 because of high rent (10 million Swedish crowns for a space of 2790 square meters) (SvD Näringsliv, 2012).

Such a retail shop is too expensive to use as a warehouse; on the other hand, too little stock will result in customers not finding what they want. The ideal would be to have an efficient system that could restock garments in one or two days, or even in hours, as they are sold. Such logistic activities require different kinds of sourcing, production, and inventory management than are currently being used.

A supply chain and logistics system must be integrated in order to reduce lead time. This imposes special requirements on the companies in the supply chain. It is an accepted fact in the industry that the demand for fashion products is difficult to forecast. Fashion markets have been characterised as open systems that are often chaotic (Christopher et al., 2004:367). For many years the trend in the textile and fashion business has been to source production in low-income countries in order to maximise gross profit margins for the company. This philosophy can have a negative impact on revenue because of the lead times necessitated by long-range forecasts ahead of sales campaigns. The danger of sourcing to such countries months before the season is an excess of inventory, a greater number of products that must eventually be sold at discounted prices, the risk that customers cannot find what they want in the shop, and ultimately a loss of profit (Mattila, King & Ojala, 2002:340-341).

A supply chain needs to be time-based, customer-orientated, and responsive to rapid changes in demand (Hoover et al., 2001:10). A company that creates an advantage for itself based on its ability to design and deliver products faster than others in the same market has been dubbed "a time competitor" (Björnland & Persson et al., 1996:53).

Christopher and Peck (1997a:64-66) list three dimensions of time-based consumption: *time to market***,** or how long it takes a business to recognise a market opportunity, translate it into a product or service, and bring it to the market; *time to serve,* or how long it takes to secure a customer's order and deliver or install the product to the customer's satisfaction; and *time to react,* or how long it takes to adjust the output of the business in response to volatile demand, that is, how quickly the supply "tap" can be turned on and off.

In this thesis *demand fulfilment time is defined as* the time it takes from when customer demand is identified to when the product is delivered to the customer. It may be subdivided into design time, production time, and transportation time. These consist of value-added and non-value added time. Value-added time is an interval in which a process such as knitting, sewing, or dyeing a garment takes place that adds something of value to the product. Non-value added time is a period of waiting between value-added processes.

It is of paramount importance to keep time to market as short as possible if one is to fulfil customer demand (Christopher, 2000:37). An example of this may be seen in a supply chain flowchart for a knitwear garment that identifies processing and inventory time and calculates value-added and non-value-added activities (Figure 2.1). Processing time (value-added activities) is shown to be 57 days, and waiting time or inventory time (non-value adding activities) is calculated at 110 days. The total lead time is thus 167 days.

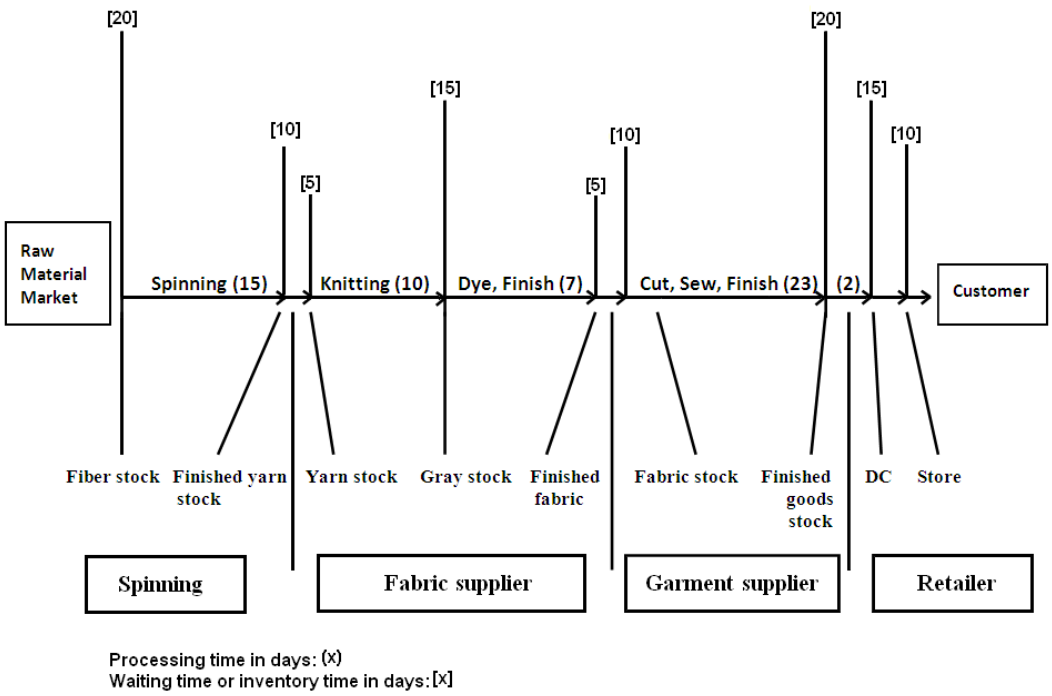

Figure 2.1. Length of supply chain in knitwear garment supply pipeline (Christopher & Peck, 1997b:80).

In the 1980s the American consulting firm Kurt Salmon conducted a supply chain analysis of the textile and apparel industry in the US that revealed the average lead time from raw material to consumer was 66 weeks (Lowson, King and Hunter, 1999:48). However, only 11 weeks were associated with manufacturing processes themselves, while nearly 40 weeks were consumed by waiting time in warehouses or in transit. The remaining 15 weeks consisted of shelf time in the store before the garments were purchased. The analysis revealed that instead of trying to minimise costs independent of one other in the different parts of the supply chain (fibre, textile manufacturing, apparel wholesaler, and retail), costs increased. Many customers could not find the style, colour, or size they sought. The store's inventory was based on forecasts made far ahead of season, so when the products became available in the shop, they were already out of fashion. The supply chain analysis suggested ways to improve the company's performance and led to the development of Quick Response (QR).

QR evolved in the US during the 1980s. According to Hines and Bruce (2007), the term was coined by Alan Hunter, a professor at North Carolina State University in 1985 to represent "a method of improving response time in the textile pipeline". QR is explained as "a new business strategy to optimise the flow of information and merchandise between channel members to maximise consumer satisfaction" (Ko & Kincade, 1997:90). Others have described it as a state of responsiveness and a flexibility strategy to reduce cost by integrating all of the players in the supply chain: raw material suppliers, manufacturers, and retailers (Lowson, King and Hunter, 1999:77). Point-of-sale information is shared upstream in the supply pipeline in order to reduce safety stocks, avoid overproduction, and minimise unsold merchandise. Those in the supply chain must adapt a variety of technologies to manage the QR concept. These include electronic data interchange (EDI), the electronic transmission of orders and invoices; computer-aided design (CAD), the use of computer technology and manufacturing; and electronic point of sale (EPoS), i.e., collecting sales information at the cash register from barcodes. Hines and Bruce (2007:2) describe QR from a retail point of view as providing customers with what they want to buy, when they want to buy it, and at an attractive price. QR is today associated with Fast Fashion, the design of new, fresh garments produced with low lead times between identified market demand to point-of-sale in a retail store (Bruce & Daly, 2006:329). The Spanish retailing chain Zara is especially known for this concept: new products are delivered to its stores several times every week, reducing the interval between a sale and its replenishment.

Four critical success factors can be identified for sourcing of seasonal products with a fashion content: forecast accuracy, process lead time, off-shore/local sourcing mix, and up-front/replenishment buying mix (Mattila, 1999:102). "High gross margins and customer service levels with as little inventory as possible" are essential for profitable retail fashion companies, according to (Mattila, King & Ojala, 2002:340). Key ratios used in evaluating profitability consist of two or more financial variables and their relationship to each other. These are often subdivided into: liquidity ratios, activity ratios, leverage ratios, and profitability ratios (McGoldrick, 1990:214). Liquidity ratios determine the ability to pay off short-terms debt obligations. Activity ratios show the firm's ability to make a profit from its resources. Leverage ratio is used to calculate financial leverage to form a picture of a company's methods of financing or its ability to meet its financial obligations. Profitability ratios in the fashion business indicate a company's ability to realise a profit from its sales.

King and Hunter, (1997:22) propose retail performance ratios that can measure the success of sourcing and how well the range of products offered by a store meets customer demand.

Fiore, Lee and Kunz (2001:100) identify the two essential elements in the MC of apparel: 1) co-design for a unique product, and 2) 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. In order to get a customised garment with a perfect fit, the client's measurements can be taken by body scanning, although some customers do not want to be scanned.

Bourke (2000), Franke and Piller (2003:582), and Weston (1997:73) have concluded that all known mass customizers' use systems that are to some extent IT-based. MC interaction platforms consist of three principal components: core configuration software to guide the user through the configuration process via questions that offer design options; a feedback tool that simulates the configuration and allows the customer to visualise the product; and an analytical tool (not seen by the purchaser) that translates the customer's order into a bill of materials and production information, then forwards the configuration to the manufacturing facility and other departments.

At one of the Factory Boutique Shima stores in Wakayama, Japan, the co-design process can be observed as the kind of tailored customisation described by Lampel and Mintzberg (1996:26) and Gilmore and Pine (1997:92). Customers browse the store for a garment they like and it becomes the starting point of the product's design. The interaction between client and store personnel is crucial as the customer proceeds to customise an item. Factory Boutique Shima's second store incorporates a prototype of a digital co-design system called Ordermade Wholegarment that allows customers to do some of the co-design by themselves in a configurator. Such an adaptive system enables a prospective buyer to alter a standard product with regard to neck style, sleeve length, and colour without assistance.

One of the impediments to applying the MC concept for manufacturing flat knitted products by complete garment technology has been the co-design process itself. It continues to require manual interaction between the customer and a shop employee throughout the customisation process. This thesis investigates expanding opportunities for MC and ways in which manual and digital co-design can be integrated with complete garment technology.

2.2 From craft to customisation in the fashion industry

Before the industrial revolution, which began in the 18th century, manufacturing was largely a craft process. A product was custom made to fulfil the requirements of an individual person. It was often expensive and therefore available only to those who could afford it (Fralix, 2001:3). With the industrial revolution and the era of mass production, more goods could be obtained by more people. Today MC has emerged as a combination of craft and mass production. The textile and fashion industry was one of the first to adopt this concept.

Tseng and Piller (2003:447) cite three aspects of apparel that must be capable of modification to be successful in an MC scheme: fit (size and shape), function (adaptability to use), and design (taste and form). Products whose physical dimensions and functional properties can be changed are more suitable for customisation then articles in which only colour and pattern can be varied. Above all, a garment must fit a customer well.

Fralix (2001:4) points to MC as the future direction of the fashion and apparel industry, but says that garment fit and colour selection have tended to restrict its use. In a review article on MC in the fashion industry, Yeung, Choi and Chiu lists companies involved in this process, including Levi's, JC Penney, Nike, and Ralph Lauren (2010:435). The authors recommended five essentials for companies who wished to succeed in the field of MC: 1) the use of a bar code system and Radio Frequency Identification (RFID) in order to track products and electronically store customer data, 2) intelligent clothing or smart textiles with enhanced functionality, such as The Gap's hooded jacket with a built-in FM radio, 3) crowd sourcing, where customers can submit and store their designs in the company's database for selling (and other customers can buy the stored designs), 4) configurators that guide clients to formulate their customisations; 5) organisational changes to create a new culture for MC on the management level.

In order to produce a customised garment with a perfect fit, the client's measurements must be determined accurately. At a retail location shop personnel can take customer measurements by hand, body scanning, or video camera (Lee & Chen, 1999:2). However, on-line shopping presents other challenges.

Body scanning has often been mentioned as a solution to the problem of perfect fit. Its disadvantages are three-fold: 1) an investment in specialised equipment is required, 2) not all people wish to be scanned, and 3) certain types of clothing require taking a customer's measurements manually. However, the impact can also be that some customers find body scanning exciting and like the experience of the process and that they also like to get the advantage of having accurate measurements. A manual procedure also enables a dialogue between the purchaser and the salesperson about the preferred fit of the garment, i.e., tight or roomy, 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. Catering to individual customer sizes becomes an even bigger problem in e-commerce.

Assuring the correct fit of a garment has been an obstacle for mail-order companies for decades. The same problem exists for MC over the Internet. Attempts have been made to solve this by having customers take their measurement themselves. The client is guided by a configurator on the company's web site. An example of this procedure has been adopted by the on-line retailer Tailor Store, which sells shirts and other products. The configurator allows a customer to customise a shirt's colour, sleeve length, and other options. Body measurements are entered into the computer, manufacturing is done in a factory in Sri Lanka, and the customer receives the product in 10 to 15 days (Estephan & Uppström, 2008; Tailor Store, 2012).

There are other examples of businesses that combine contemporary manufacturing technologies with MC as shown in Table 2.1. One is the Finnish Left Shoe Company (formerly known as The Leftfoot Company), where each customer's feet are scanned by sales personnel. The information obtained is then used to manufacture perfectly fitting shoes that are delivered to the customer within three weeks (Sievänen & Peltonen, 2006:487). The internet-based German company Spreadshirt sells t-shirts whose graphics are individually designed by customers and then produced on standard t-shirt selections using modern digital print technology (Reichwald & Piller, 2006:51).

Brooks Brothers, an upscale American apparel company founded in 1818, now offers mass customised, made-to-measure suits and shirts based on individual body sizes and preferences in partnership with Pietrafesa Corp., a private label suit manufacturing company from Liverpool based in New York (Rabon, 2000:40; Yeung et al., 2010:442-443). Information technology and manufacturing processes were developed and a system called eMeasure introduced in 17 Brooks Brothers stores. The customer's dimensions are taken by a body scanner in the shop and those measurements are used to produce suits and shirts with a perfect fit. The eMeasure system also can store measurement profiles and quickly recall information for repeat customers. Many examples of MC now exist in the fashion industry, and the Internet continues to open up more possibilities for the future.

For a business to be engaged in the sale of mass-customised products, the traditional structure of development, production, and distribution needs to be reformulated from a linear to a concurrent or parallel process (Anderson, 1997; Kincade & Regan et al., 2007:630). Closing the sale with a customer becomes one of the initial steps in a retail transaction, rather than the final one. From that point, streamlining time-consuming manufacturing operations after the point-of-sale is the key to shortening delivery time. Situating the manufacturing process after the point-of sale eliminates or reduces a company's inventory of ready-made garments and may increase its stock-turn percentage.

Table 2.1. Descriptions of MC examples.

Companies	Products	Descriptions
Tailor Store	Shirts	- Swedish on-line retailer - on-line configurator - customers take their own measurements - manufacturing in Sri Lanka - delivery to customer in 10 to 15 days
The Left Shoe Company	shoes	- Finnish on-line retailer - customers feet's are scanned in the store - delivery to customer in three weeks
Spreadshirt	t-shirts	- German on-line retailer - graphics individually designed by customers - digital printing technology is used - customers can sell their designs to other customers in Spreadshirt's on-line shopping system
Brooks Brothers	suits	- American apparel company - made-to-measure suits - eMeasure system for measurements in 17 Brooks brothers stores - body scanner in the shop - customer measurement profiles are stored and used for repeat orders

2.3 Knitting Technology

2.3.1 Knitting definitions and concepts

There are three methods of producing textile fabrics from yarn: 1) interlooping, 2) interweaving, and 3) intertwining and twisting (Spencer, 2001:1-3).

Interlooping involves forming a stitch (or loop) that is released after another stitch has been formed and intermeshed with it. In this way a ground loop structure is created. Knitting is the most common method of interloping. (Spencer, 2001:2). All knitted structures can be further subdivided into weft knitting and warp knitting. In weft knitting the yarn runs horizontally across the structure, whereas in warp knitting it goes vertically through the knitted structures (Figure 2.2). Weft knitting is mainly used for garments that require stretchability and elasticity.

Warp knitting commonly is used for clothing, as well as home fabrics and technical textiles. Different machines are employed in each technology and each method has its own strengths (Raz, 1993:20).

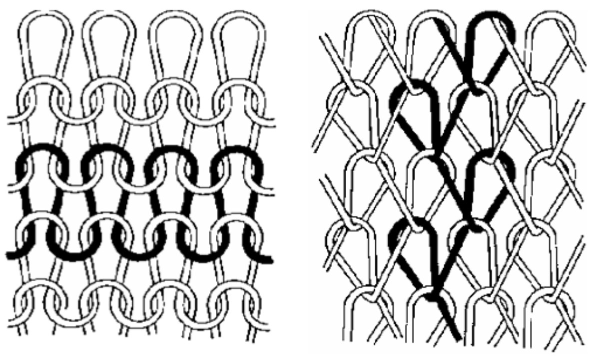

Figure 2.2. Two kinds of knitted structures: weft knitting and warp knitting (Raz, 1993:17).

Apparel produced by knitted structures can either be in tubular (hosiery) or flat form, (sweaters, skirts, underwear). Weft knitting machines can be subdivided into flat knitting and circular knitting machines, depending on the form and formation of the needle beds. Flat knitting machine have needle beds that are aligned lengthwise and often equipped with independently moving latch needles. Circular knitting machines consist of one or two round needle beds with radial or parallel needles.

The main difference between flat and circular knitting machines is the shape of the fabric each produces: flat in the case of the former and tubular in the latter. Circular knitting machines have much higher productivity then flat knitting machines because of the greater number of knitting systems feeding yarn into the machine. The number of systems in a flat knitting machine is limited by the linear construction of the needle beds. The advantage of flat knitting machines, however, is their versatility and the ability to knit various loop structures, patterns, and combinations of structures.

2.3.2 Production methods for flat knitted fashion garments

Flat knitting machines traditionally produce knit panels with coarse structures, a fixed edge, a welt at the bottom of the panel, and patterns such 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 method and type of machinery used. The process consists of several operations, as shown in Figure 2.3.

Figure 2.3. Production process for flat knitted garments (Brackenbury, 1992:170).

The knitting process begins as yarn-on-yarn cones are knitted to panels in the flat knitting machine. The panels are often steamed in a finishing stage after knitting. Then the panels are cut to size and shape, and sewn together into a garment. To achieve the desired level of quality, the garment may be finished by steaming or washing. Traditionally, the manufacturing process subjects coarse flat knitted garments to several time-consuming operations after knitting.

Flat knitted garments can be manufactured by four distinct production methods: 1) cut & sew, 2) fully-fashioned, 3) integral knitting, and 4) complete garment.

2.3.2.1 Cut & sew

Cut & sew is a common method of producing flat knitted garments. Panels for front, back, and sleeves are knitted in a rectangular form and then cut into shape (Figure 2.4) (Choi, 2006:18; Brackenbury, 1992:10). The panels are then sewn together, and separately knitted trimmings and pockets are attached to complete the garment. Both cutting and sewing are post-knit processes that take place away from the knitting machine. Up to 40% of the original fabric may be wasted as cut-loss in cut & sew (Choi, 2006:18). The advantage of this type of production, however, is that it can be done on all flat knitting machines, including older models that do not have computer processing systems. The disadvantages are the labour intensive post-knit processes, including cutting and sewing.

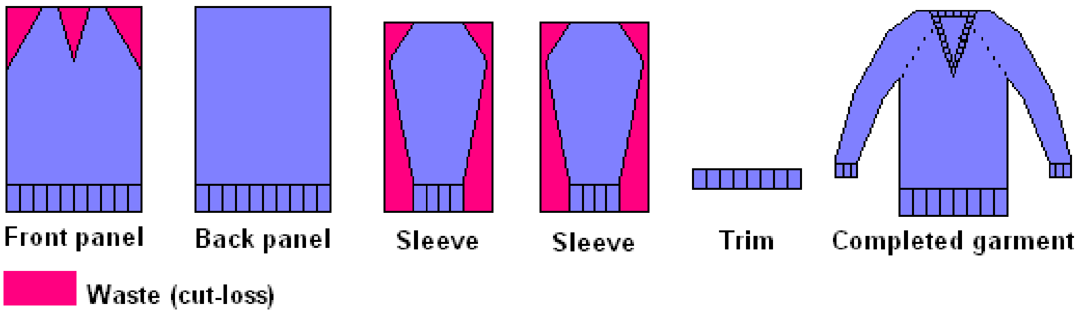

Figure 2.4. Cut & sew production method.

2.3.2.2 Fully-fashioned

Fully-fashioned, or shaped knitting, is a method of production in which the front, back, and sleeve pieces are knitted in the right shape directly in the knitting machine (Choi, 2006:18-21; Raz 1993, 467-473). The cutting process is either minimal or eliminated entirely, but some post-knit cutting may still be necessary. Trimmings and pockets are knitted separately and sewn together with the rest of the knitted elements to complete the garment. The benefit of this production method is that cutting is generally avoided, making material consumption and labour costs lower than the cut & sew production method showed in Figure 2.5 (Brackenbury, 1992:16).

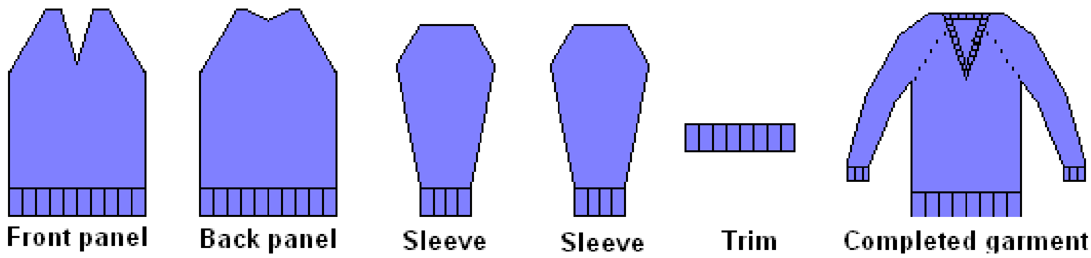

Figure 2.5. Fully-fashioned production method.

2.3.2.3 Integral knitting

Integral knitting is a method by which trimmings, pockets, buttonholes, and other design features such as bindings and decorations are directly knitted into the fully-fashioned produced panels as shown in Figure 2.6 (Spencer, 2001:193; Choi & Powell, 2005:20). This technique results in fewer post-knit processes. Compared with cut & sew and fully-fashioned production methods, savings may be had in labour and waste, and in post-knit sewing processes as well. Both the quality and appearance of the completed garment can be improved by this method of integrating ornamentation into the panels directly in the knitting process, reducing both cut-loss and post-knit operations to a minimum.

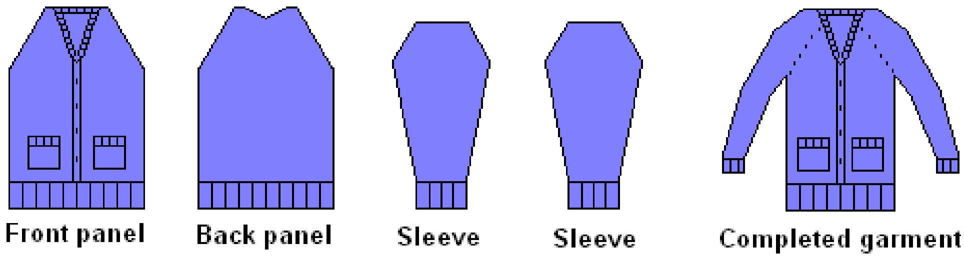

Figure 2.6. Integral knitting production method.

2.3.2.4 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 decorative elements in place as presented in Figure 2.7 (Choi & Powell, 2005:1). The advantage of this technique is no waste of material (cut-loss) and no expensive post-knit operations (sewing or cutting) (Legner, 2003: 240). Depending on the style of the garment, some minor cutting and sewing of labels or trim may still be necessary. In addition, while panels sewn together using other manufacturing techniques run the risk of having variations in colour shades between the panels because they were knitted with yarn from various dye lots, in complete garment technique all the yarn comes from the same cones, enabling higher quality and reducing problems of colour mismatch. With seamless technology, the garment can be made to fit perfectly and be comfortable to wear. In summary, manufacturing processes are reduced and knitting is done on-demand, which can shorten production lead time considerably (Legner, 2003:240).

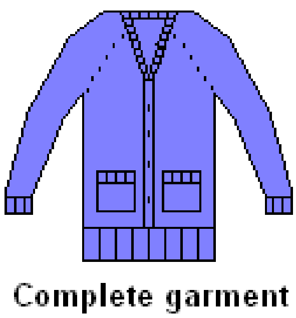

Figure 2.7. Complete garment production method.

2.3.3 Development of complete garment technology

Although complete garment technology was introduced in the 1990s, it has a long history. The first mechanical knitting machine was a stocking frame developed by an Englishman, William Lee of Calverton, near Nottingham, in 1589 (Grass & Grass, 1967:59). What made it possible for Lee to build a machine that could make loops mechanically was his invention of the bearded needle. These needles were set in a row and worked together with a "presser" to form loops in the knitting frame.

The invention of the latch needle by Mathew Townsend of Leicester in 1847 brought about a further advance in knitting technology. Townsend's needle consisted of a needle hook, a needle stem, and a latch. The main advantage of the latch needle was that no presser was needed to close the gap that lets the yarn slip over the top of the needle in the loop forming process. The latch needle is self-acting, so that the movement and control of the needles allows loop selection to be done (Spencer, 2001:24). The first V-bed flat knitting machine was patented by Isaac Wixom Lamb of Perry, Michigan, in 1865. Lamb displayed his machine at the 1867 Paris World's Fair, where it won first prize. He later went on to establish a factory to produce knitted gloves and mittens in the US. Henri Edouard Dubied bought the European rights for Lamb´s machine during the exhibition in Paris and started his own machine building factory (Spencer 2001:224). A German engineer Heinrich Stoll began to repair Lambs machines and later (1890s), he began to build machines under the brand name Stoll. Around the same time (1864), a patent for a flat bed knitting machine that could knit fully-fashioned panels was awarded to William Cotton of Loughborough, England (Spencer 2001:194).

In the 19th century flat knitting machines were equipped with sinker in order to control the loops in the knitting process and used for tubular single jersey products as socks and gloves (Hunter, 2004a:19). According to Hunter a knitting process for the production of shaped knitted shirts was developed and patented in the USA in 1940. The aim was to improve drape and fit but also to cut manufacturing costs by shaping in the knitting machine. In 1955 traditional Basque berets containing shaped sectors were automatically knitted by decreasing the number of needles in action during knitting (Hunter, 2004a:19). The Courtaulds company in the UK worked during the 1960s on the idea of producing garments by joining tubes for body and sleeves. The method was too advanced to be commercialized at that time.

In 1995 the Japanese company Shima Seiki exhibited the first complete garment knitting machine at the International Textile Machine Exhibition (ITMA) in Paris. This was a breakthrough after many efforts to produce a knitted garment ready-made directly in the knitting machine, but without the post-knit processes of cutting and sewing. Over 400 years elapsed from the invention of the first knitting frame to the development of a machine capable of knitting seamless garments (Hunter, 2004a:18-21).

One of the many technical issues that had to be solved was the “take-down”. A flat knitting machine requires a way of controlling a previously-shaped loop during the formation of a new stitch. To achieve this, tension is applied to pull the fabric down, usually by drawing it through take-down rollers. However, in order to hold down the knitted loops, tension on all the needles must be equal over the whole width of the fabric (Hunter, 2004a:18). Unequal tension will cause the loops to be lost and result in faults in the knitting. Because of the need to equalise tension on needles along the needle bed, only rectangular panels or panels that were shaped equally at all selvage edges could be knitted. The challenge in producing integral knitting is 1) to engage some groups of needles on the needle bed in knitting, while 2) other needles rest, and 3) the stitches produced earlier continue to be held down. This type of integral knitting is not possible with a conventional take-down system, and so the solution to the problem has been the key obstacle to developing a complete garment machine over the years. Some have tried to use loop controlling sinkers to hold down previously-shaped loops while the needles moved up to form new ones. According to Hunter, (2004a:19), this was first attempted in order to produce tubular single jersey articles.

The technique of employing hold-down sinkers was adopted by Shima Seiki in the 1960s in their glove knitting machines. During the same decade the Courtaulds Company in the UK developed a method of knitting three separate tubes (torso and sleeves) and joining them together at the shoulder. It proved too difficult for the knitting machines available at the time but resulted in a number of patents that became important later. The problem of controlling finished loops as new ones were formed remained the main challenge. Then a take-down device similar to one on conventional hand-knitting machines was tried.

On hand-operated machines it had always been possible to begin knitting on empty needles in order to control the take-down tension: the yarn carrier lays the thread in the hooks of the needles and a thin wire in a comb with a weight serves as a take-down device (Hunter, 2004a:20). It took a long time to accomplish this hand-knitting machine technique on power driven flat machines. Eventually, the presser foot device was borrowed from existing knitting machines. It was similar to the previously mentioned loop-controlling sinker but could work without tension being applied by a take-down device from below. This innovation depended on a bent wire travelling with the carriage over the needle beds and pressing down the fabric between the front and rear beds. Its advantage was that the presser foot could keep the previously knitted loops low down on the needle stems when those needles rose to form new stitches, relieving the take-down system from being the only device to control the previously knitted loops. The concept was gradually developed and, as improved computer programming systems began to control the functions of knitting machines, the goal of knitting a complete garment on a machine came closer to being realised.

In 1985 Courtaulds and Shima Seiki agreed to a joint research project to develop technology for the production of integral garments. Shima Seiki's glove knitting machines had already solved an earlier problem by adopting the comb and wire hand-machine take-down technique and they were now manufacturing modern flat knitting machinery with this device. Then, at ITMA in Paris in 1987, the German company Stoll GMBH unveiled the CMS, a knitting machine with two new developments: hold-down sinkers, which performed the same function as the presser foot, and short-stroke knitting, where the carriage only moves over needles that are in operation, then turns in the opposite direction. Short-stroke knitting reduces knitting time considerably, especially when making shaped panels. In 1989 Shima Seiki introduced the SES 122FF, a compact 40-inch wide machine with short-stroke knitting capability, set-up comb, presser foot, an ordinary take-down device, and extra take-down rollers to control fabric more accurately (Hunter, 2004a:21). These developments, combined with computerised programming systems, brought the goal of knitting seamless garments on a machine within reach.

When Shima Seiki's first complete garment machine appeared in 1995, it used alternate needle technique to knit the product. Complete garment manufacturing requires the full course of a rib to be knitted on each needle bed during one traverse in order to form the front and back side of the tubular garment component (Spencer, 2001:239). With alternate needle technique, used in knitting full ribs, Milano ribs, and other two-bed rib structures, the machine must knit on alternate needles while the remaining needles remain empty. To achieve this, a course of full-rib structure is knitted on two needle beds and then transferred to one bed. The needles in the receiving needle bed must then be empty. The other rib structure is then knitted, the loops transferred, and the whole procedure repeated in a programmed sequence of knitting and transferring loops. However, knitting on alternate needles can affect the fabric adversely because it is under tension. The solution offered by Shima Seiki was a machine with four needle beds, two for each rib row of the tubes being knitted. This allows knitting on all needles simultaneously, instead of on alternate needles, and results in a fabric with more stretchability. However, a machine with four needle beds is very expensive because of the extra beds and their cam plates. Nevertheless, complete garment or seamless knitting on V-bed flat knitting machines allows higher productivity and the possibility of adopting quick response production and logistics concepts (Hunter, 2004c:20; Legner, 2003:240; Mowbray, 2002:22; Choi, 2006:16).

2.3.4 Complete garment technology, MC, and logistics in combination

When Shima Seiki launched their complete garment concept in 1995, they used the name WholeGarment (Spencer, 2001:237). Stoll from Germany named their production technology Knit & Wear (Choi & Powell, 2005:24). Both are brand names and registered trademarks. Since the different terms for making knitted garments with a minimum of post-knit operations can be confusing, we will refer to this flat knitting technology as *complete garment.*

Although the first complete garment flat knitting machine appeared more than fifteen years ago, there have been some difficulties in convincing companies to adapt this new technology. The cost-saving benefits, with no material cut-loss and a minimum of post-knit processes, make complete garment technology appear likely to be one of the future production methods in the supply chain for knitted garments. However, in order to gain all the benefits of this technology, adaptations of both the production system and the supply chain to a new logistic concept is necessary: simply buying a new kind of knitting machine and installing it in the same production and business system as before will not lead to the desired outcome. New technology takes time to implement in an existing supply chain, especially if the whole chain must undergo modification.

The leading machine manufacturers Stoll and Shima Seiki have no machine for cut & sew without the capability of producing fully fashion. The difference in cost between a fully fashion machine and a complete garment machine is about 30% depending on equipment on the machine M. Legner, Stoll stated in an email on 27th September 2012.

One aspect in this context as previously mentioned, is that complete garment production does not require as much cutting and sewing as the other production concepts. MC will continue to expand its applications in manufacturing fashion products. In many countries, especially in northern Europe, where chains dominate the garment industry, consumers are tired of finding the same merchandise in stores and want something new. One of the retail concepts of the future may be MC. It offers a customer the opportunity to be a ‘designer for a day’; the experience of creating a unique product that has never been worn by anyone else. When MC is merged with a second new technology, Internet shopping, it gives customers the opportunity to shop from home at any time they please and have the product delivered directly to their door—especially as the problem of obtaining measurements has largely been overcome by graphic instructions and on-line help.

Complete garment technology will continue to evolve and create expanded market share for flat knitting machines. It is following the same trend as hosiery machines: the reduction of processes with a product that is almost completely finished as it comes off the machine. Historically, the main reason for long lead times has been the presence of several non-value-adding activities throughout the supply pipeline. These activities may now be reduced or eliminated entirely, especially in the manufacturing process, without diminishing the total value added to the product. This has been the proven way forward in manufacturing: minimising processes in order to make a product as efficiently and inexpensively as possible. The implementation of complete garment technology in combination with MC in a supply chain for fashion products may result in measurable benefits:

- Reduction in manufacturing lead times
- Garment custom-knitted close to point-of-sale
- Fast order fulfilment for the customer
- A positive customer shopping experience

If the production system and the supply chain are adapted to this new logistic concept, the time from yarn to finished garment will be greatly improved. The possibilities for complete garment technology, despite some current limitations in structures and patterns, are increasing every year.

The question remains: Can MC, in combination with complete garment technology, be applied to all types of garments and products, or are there some garments it is not suitable for? For commercial reasons MC is probably most suitable for products in the middle and upper price range because the mass customisation process often makes them more expensive than mass-produced products. Almost all of the materials commonly used in flat knitting can be employed in making complete garments. Although MC in this research focuses on fashion garments, it can probably be applied to technical textiles made with complete garment knitting technology due to the ability of complete garment machines to produce three-dimensional structures with no waste of material. However, this is an application that remains to be developed and is beyond the scope of the present study.

3. METHODOLOGICAL FRAMEWORK

3.1 Research approach and procedure

The choice of a research approach is largely determined by one's objective. Factors such as access to research data, funds available, and the researcher's background also influence the choice. The methodology used here is based on a mixed method design that relies on inductive reasoning and does not require a hypothesis as its starting point. As shown in Figure 3.1, existing theoretical knowledge derived from prior research is studied, real-life observations are made, and the conclusions drawn are analysed to create more general theories (Kovács & Spens, 2005:137). The research questions are studied with various methods to collect complementary data and to conduct analyses. This type of design allows more complicated research questions to be addressed and stronger evidence to be found than is possible by a single method alone (Yin, 2009:63).

The main methods used to gather research material for this thesis have been the qualitative multiple-case study defined by Yin, (2009:53), quantitative simulations (Banks et al., 2004), and action research (Näslund, 2002:330). These three are the basis of the individual journal articles appended.

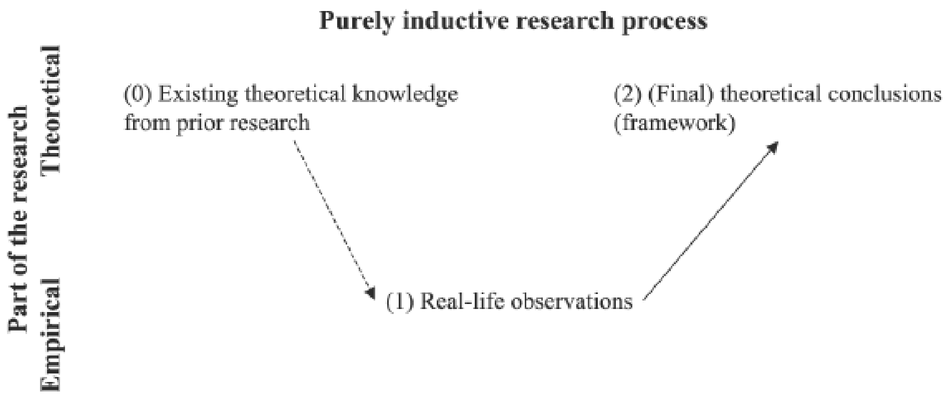

Figure 3.1. Purely inductive research process (Kovács & Spens, 2005:137).

Three types of case study research designs—exploratory, explanatory, and descriptive—are identified by Hancock and Algozzine (2006:33), who describe exploratory design as seeking "to define research questions of a subsequent study or to determine the feasibility of research procedures. These designs are often a prelude to additional research efforts and involve fieldwork and information collection prior to the definition of a research question". Exploratory design characterises the literature study and the interviews performed in the first article. The literature research was then continued and the frame of reference was divided into three parts: knitting technology, fashion logistics, and MC, leading to the formulation of the questions to be investigated in the subsequent studies. The design consists of a frame of reference, principal questions, multiple case studies, action research, and simulations in which empirical data were gathered and analysed. The methodology is further described in the individual articles.

3.1.1 Action research

A frequently used definition of action research is by Rapoport, (1970:499), as cited by Näslund, Kale, and Paulraj (2010:332): "Action research aims to contribute to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually acceptable ethical framework."

Knit-on-Demand is a research project whose overall purpose is to explore a new means of bringing agility into the fashion industry. Our aim was to develop a shop for customised knitted garments built on complete garment technology and study this shop's performance in a combined retail and production environment. The co-design process, the layout of the store, the garment manufacturing techniques, and logistics were all determined by action research. McNiff and Whitehead (2002:41) describe the steps in the action process as planning, acting, observing, and reflecting. These steps follow each other as successive loops (Figure 3.2).

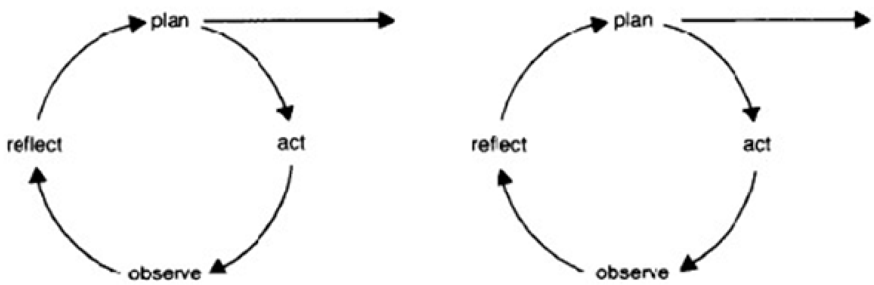

Figure 3.2. Sequences of action-reflection research loops (McNiff & Whitehead, 2002:41).

The researcher takes an active part in the process, rather than being a passive observer, as is common with more conventional methods. Eight follow-up steps are suggested by McNiff, Lomax and Whitehead (1996:71).

1. Study current processes
2. Identify what to change and develop
3. Think of how to proceed
4. Test it

5. Validate the result
6. Change the plan, reflect, and act again
7. Evaluate the modified action
8. Continue the cycle until the work is done

Action research as used in combination with supply chain management and logistics in the Knit-on-Demand project was described by Larsson's 2011 work. The present thesis mainly employs action research methodology in Article 2, "Knit-on-Demand: Development and simulation of a shop model for customised knitted garments", where processes were studied, the concept was developed, and it was tested in simulations. This loop of actions was performed several times with validation of results and change of settings between the loops.

3.1.2 Case Studies

Yin (2009:18) defines the 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." Orum, Feagin and Sjoberg (1991:2) consider the case study appropriate for a holistic, in-depth investigation that often is based on the use of several data sources. Gill (1995:72) states that "the case study is a research strategy which focuses on understanding the dynamics present in single settings and may rely on evidence which may be qualitative, quantitative or, frequently, a combination of both." Yin (2009:27) suggests that five components are essential in a case study:

1. The question to study
2. Its propositions, if any
3. The units of analysis
4. Linking data to propositions
5. Interpreting the findings

Case studies may have single or multiple designs. Proof from multiple cases bears greater conviction and produces research that is more robust (Yin, 2009:53; Herriot & Firestone, 1983:14). Multiple case designs are generally superior to single case designs, which are susceptible to error. Another advantage to having two or more cases in a research design is that contrasting cases can be selected and, if their results agree, the outcome will bear more weight than a single case study (Yin, 2009:61; Eilbert & Lafronza, 2005:191-192).

The case study presented in Article 3, "MC of knitted fashion garments: Factory Boutique Shima: A case study," was selected because it represents the only known example of a retail concept combining MC with complete garment technology. It also contains data about essential fashion logistic factors that are important for the research questions. The case studied in Article 4, “MC of flat knitted fashion products: Simulation of the co-design process,” explores the main element in joining customisation with complete garment technology. The case study in Article 5, “The Knit-on-Demand supply chain,” examines another retail concept combining MC and flat knitting production. All of the studies are used collectively to answer the research questions addressed in the thesis.

3.1.3 Simulations

“Many complex systems in the physical sciences are studied by developing models of their underlying physics on a computer, and by using computationally intensive methods to learn about the behaviour of those systems. These methods are called ‘simulations’ or ‘numerical experiments’ (Winsberg, 2003:105). A simulation like those described above can be defined as the artificial representation of an actual system. It can be run by a computer or carried out manually, but it enables conclusions to be drawn about the real system (Banks et al., 2004:3). A model should contain details, but no more than necessary to provide the desired results. When using a simulation, it must be implemented accurately, following a series of steps: 1) conceptual design: the user must decide what is to be modelled; 2) code development: a simulation program must be constructed or an existing program chosen; 3) validation: the results must make sense; 4) experimental design: the variables must be manipulated under experimental conditions; 5) implementation: the experimental design must be executed; 6) analysis: the output data needs to be analysed; and 7) interpretation: the simulation results need to be linked back to theory (Dooley, 2002:829-848).

The simulation models used in this study are of the discrete-event simulation type. A model represents the components of a system. It is time-based and its result is a product of the interactions of system components. The discrete simulation employed in the process-interaction method emulates the flow of an object through the system. The object continues to advance until it is delayed, enters an activity, or has been completed. When the object is stopped, time is advanced to the next movement. The 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 et al., 2004:67).

In-data for the simulation of Production lead time data is based on information from machine equipment companies and trials at the Swedish School of Textiles (Nilsson & Olofsson, 2006). Parameter values such as data of customers entering store (arrival rate of customers) is based on a study made by students in a Six Sigma course at University of Borås. The study was conducted at the fashion shop where the Knit on Demand shop was intended to be situated.

Simulations are used in Articles 2 and 4. Data was gathered, evaluated, and the simulation performed using AutoMod software. In Article 4, such a simulation compared manual and digital co-design by means of AutoMod.

3.1.4 Interviews and observations

Research projects commonly use interviews and observations to collect information and data for further evaluation. Conversations with professionals or key persons in an actual situation can provide a valuable overview of a situation as well as substantive details. As Olsen has summarised it, "In qualitative data collection, the interview plays a central role, because in the conversation lies the potential for understanding changing viewpoints, sign systems, contexts and intentions" (Olsen & Pedersen, 2005:214).

Repeated interviews with the same persons, or talking with several people representing different aspects of an issue, can provide a comprehensive view of what is being studied. Our objective was to gather sufficient information about processes, equipment, and lead times to inform the research problem. Interviews for the articles were conducted as conversations on-site, by telephone, or through e-mail. The responses were then analysed. For Articles 3 and 4, interviews and observations of customers and shop personnel were made during the co-design process.

3.2 Research process

The Knit-on-Demand research project began in 2006 as an attempt to develop a business concept utilizing complete garment knitting technology. This study was based on five peer-reviewed articles written over a seven-year period. Figure 3.3 outlines the research process pursued.

The first article was exploratory. It began to investigate how to combine fashion logistics with complete garment knitting technology and consisted of a literature review and interviews. One of its findings was that if a business and supply chain were designed to respond quickly to customer demands for fashion products, complete garment technology could play an important role in the system. It opened up the possibility of combining complete garment technology with MC. The study was presented at the PLAN conference in Borås, Sweden in August 2005, and at the AUTEX Conference in Raleigh, NC, in June 2006, and published in Autex Research Journal in December 2007.

Article 2 was the first attempt to develop a shop and production model for the Knit-on-Demand concept incorporating complete garment technology. The study was presented at the ITMC Conference in Casablanca, Morocco, in November 2007 and published in International Journal of Fashion Design, Technology and Education in July 2008.

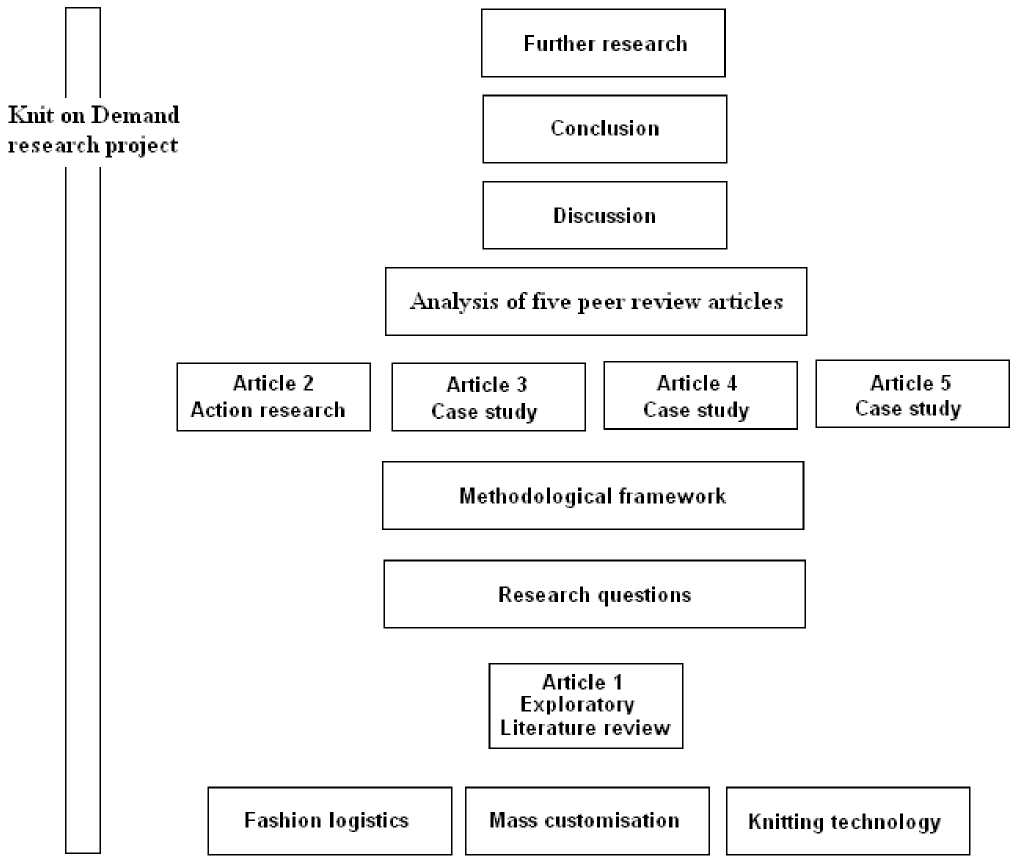

Figure 3.3. Research process.

Article 3 was the case study of an existing MC concept for knitted products. The empirical data was collected on-site at Factory Boutique Shima in Wakayama, Japan. The study was presented at the Textile Institute World Conference in Hong Kong in November 2008 and published in International Journal of Mass Customisation in January 2010.

Article 4 was a case study comparing manual and digital co-design with most of the data supplied by Factory Boutique Shima. The study was presented at the MCP-AP Conference in Taipei, Taiwan, in December 2010 and published in Autex Research

Journal in March 2011. Article 5 describes Knit-on-Demand case study from a supply chain perspective and considers design, technology, logistics, and performance and was published in Autex Research Journal in 2012. The chronology of the research is shown in Figure 3.4.

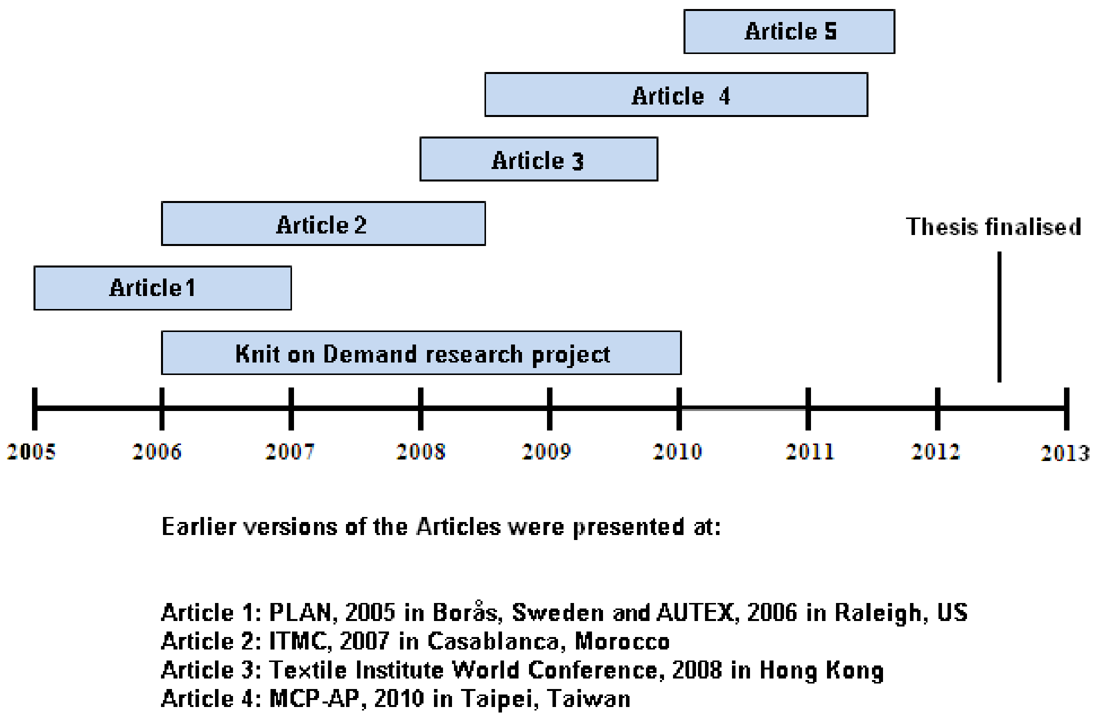

Figure 3.4. Research chronology.

3.3 The research gap

The research gap was identified by a literature review. Complete garment knitting technology is a niche area in textile technology. It is difficult to find research literature on the subject, especially in combination with MC and fashion logistics. Mowbray has interviewed the managing director of Shima Seiki about the future of complete garment production. Savings in cost and time, high productivity, and quick response were identified as advantages (2002:22). The possibilities of using complete garment machines for the production of mass customised products are discussed by Choi and Powell (2005:6) and Choi (2006:16).

There are a number of articles and some books describing and discussing integral knitting and complete garment technique (Spencer, 2001:193; Mowbray, 2002:22; Hunter 2004a,b,c), all of which presents the history, technical aspects and an overview of the subject. However, none of these sources provide a deep picture of the complete garment technique in combination with MC of fashion garments.

While there is some research on the significance of fashion logistics and agile supply chains (Christopher et al., 2004:367); Mattila et al., 2002:341; Lowson, King and Hunter, 1999:28), little has been written about the fashion logistics effects of complete garment technology combined with MC.

In the fashion industry in general, knitting has played a vital role for more than five hundred years (Grass & Grass, 1967; Spencer, 2001:7).In MC, the importance of the co-design process between the company and the customer has been a major concern for more than thirty years (Toffler 1980:200; Wikström, 1996:360; Piller, 2004:315**).** However, if we are to argue that MC provides a complement to mass production of knitted garments**,** it remains a matter of concern that there are no research-based studies for this type of co-design in combination with complete garment technology.

This thesis will suggest a number of research questions which need to be addressed when considering the combination of these three areas and the technical aspects for development of such a concept.

3.4 Data analysis methods

The data analysis methods applied were (1) triangulation, (2) cross-case synthesis, and (3) value stream mapping. Data triangulation and value stream mapping were used in the analysis in RQ1 and cross-case synthesis in RQ2.

3.4.1 Triangulation

Triangulation is a way of taking more than one approach to answering a research question in order to enhance the strength of the conclusion. The results may be double (or triple) checked, a process also called "cross examination." By combining theories, methods, observers, and empirical materials in research, it is possible to overcome weaknesses, biases, and problems in analysing the results (Patton, 2002:555; Alvesson & Sköldberg, 2008:179; Gummesson, 2000:142). As cited earlier, findings can be more assured if different methods lead to the same result, whereas if only one method is used, results may be misleading. Two methods may inconclusively point in different directions. However, three methods may result in two of the three approaches giving similar answers. Negative lessons are also valuable: if all three findings are in disagreement, the question has to be reformulated.

Four types of triangulation have been categorised (Yin, 2009:116; Patton, 2002:556).

1. Methodological: using different data collection methods
2. Data: analysing accuracy of different data sources with the same method
3. Investigator: using more than one analyst or observer to review findings
4. Theory: using multiple theoretical perspectives to interpret data

Methods triangulation has been used for the analysis of RQ1 to compare the results from Articles 2, 3, and 5. Such a multiple approach combining quantitative and qualitative techniques provides a more complete set of findings than could achieved through the use of a single method. Thus, triangulation is used in order to check the validity of the research data.

3.4.2 Value stream mapping analysis

Value stream mapping is a technique used to identify and eliminate waste in a production flow (Hines & Rich, 1997:46; Womack, 2006:145). Three types of operations are performed in internal manufacturing; (1) non-value adding; (2) necessary but non-value adding; and (3) value-adding (Hines & Rich, 1997:47). Non-value adding is categorised as pure waste with actions such as waiting time, double handling and storage of halffinished products. Those activities could be eliminated or reduced without reducing the total value added to the product (Mattila, 1999:48). Examples of necessary but non-value adding operations are actions necessary under current circumstances, for example walking long distance to pick up tools or material. The Toyota production system (TPS) refers to seven sources of waste that are common: (1) over-production; (2) waiting; (3) transportation; (4) Over-processing; (5) unnecessary inventory; (6) unnecessary motion; (7) defects (Hines & Rich, 1997:47).

In this study the aim was to compare the time it takes to manufacture a complete garment knitted product with a fully-fashioned product. The value stream mapping is adapted for this purpose from the process activity mapping described by Hines & Rich (1997:47). This means that the flow in the manufacturing of a garment was studied and divided into sub-processes and preparation procedures. This was done for the fully-fashioned and complete garment machines separately and activities in each sub-process were noted and boundaries between processes determined. Lead times for each process were collected and the total lead time for complete garment and fully fashion manufacturing calculated. The mapping process was carried out as follows:

1. Process activity mapping
2. Boundaries between processes determined
3. Process times collected
4. Preparation times collected
5. Summary of lead time results
6. Comparison of results

Only processes in the value chain that differ between the two technologies were mapped.

3.4.3 Cross-case synthesis

Cross case synthesis refers to the analysis of two or more cases. The analysis is often easier and the findings more likely to be definitive than having only one case to examine. Although cases are treated separately, synthesising the data substantiates the findings that seek to respond to the research questions (Yin, 2009:156). A cross-case synthesis may be carried out whether the individual case studies were a predesigned part of the same study or if they were independent research studies: generalisations are sought across a number of studies.

In Articles 2, 3, 4, and 5, the case study method is applied by gathering data through simulations, interviews, and observations. Cross-case synthesis is used to analyse the data in those articles and form the basis for answering the research questions.

3.4.4 Summary of scope, aims and methods

The following Table 3.1. characterises the scopes, aims, methods and the empirical sources used in the five articles appended to the thesis. The methods used in the articles have been selected to suit the scope and help answering the research questions in each individual article.

Table 3.1. Summary of scope, aims and methods in articles.

Art	Scope	Aim	Main methods	Empirical sources
1	Research questions	*Explores* three areas of research	Literature study, interviews	Knitting machine manufacturers
2	Order fulfilment process with customisation and production	*Develops and describes* a store and production concept with complete garment technology	Case study, action research, simulation	Knit-on-Demand project
3	Co-design and production process	*Describes and evaluates* customisation concept	Case study, interviews, observation, SWOT[a] analysis	Shima Seiki; Factory Boutique Shima
4	Co-design process	*Develops and describes* simulation of manual and digital co-design	Case study, simulation	Knit-on-Demand project; Factory Boutique Shima
5	Knit-on-Demand research project	*Maps* Knit-on-Demand supply chain	Case study, value stream mapping	Knit-on-Demand project

[a] SWOT (Strengths–Weaknesses–Opportunities–Threats)

4. RESULTS

The results of the appended articles are used to answer the research questions stated at the beginning of this thesis (Table 4.1). The sign "X" denotes that in this article there is information to help answer a research question under the specific subject.

How can complete garment knitting technology be applied in a retail concept for customised garments?

Table 4.1. Relationship between the research questions and the articles.

	RQ1	RQ1	RQ1	RQ1	RQ2
Article #	*Demand fulfilment time*	*Sell-through*	*Lost sales*	*Stock turn*	*Co-design*
1	X		X		
2	X	X		X	X
3	X	X	X	X	X
4	X				X
5	X	X	X	X	X

4.1 Article 1

4.1.1 Purpose and overview

Article 1 uses an inductive approach, together with general system theory and feedback, a literature survey, fashion production company visits, and information from suppliers of knitting production equipment, to examine how different parts of the system affect the others. The launching of the first complete garment flat knitting machine in 1995 was a major step toward making the manufacturing of flat knitted garments more efficient. During the years that followed, advances in machinery rapidly increased the range of styles, patterns, and structural possibilities. However, this new technique did not revolutionise the industry, as many had expected. Some complete garment knitting machines were purchased, but older types of manufacturing techniques continued to dominate the market. Knitting machine producers had difficulties persuading knit manufacturing companies of the benefits integral and complete garment knitting technology offered. Our purpose here is to explore flat knitting production techniques, especially complete garment knitting technology, to determine the advantages and disadvantages they present from a logistics and a technical point of view in the business of fashion retailing.

4.1.2 Principal findings

Traditional production systems for manufacturing knitted garments no longer correspond to the fast-paced requirements of modern fashion retailing. To be successful, the fashion and retailing industry of today must be able to respond to rapid changes in fashion. It must also keep pace with the necessity of producing many sizes and colour combinations for one fashion model, each with their own SKU. Modern production and logistics systems must be capable of supplying retailers with merchandise they can put on display in the shop and fulfilling the customer's needs in a timely manner. If production and logistics are too slow, especially for high fashion products, there is the likelihood that when a customer wishes to purchase a specific high fashion garment, the store will not have it and the sale will be lost. If the system has too great a time lag, there is a considerable risk stores will be left holding goods that have to be sold at reduced prices. On the other hand, a well-organised, quickly responding supply chain will provide customers with what they want while their interest is still high, resulting in a greater sell-through for the retailer.

The complete garment concept is ideally suited for a 'fast-to-the-market' supply chain, where all parts of the pipeline are focused on fulfilling customer demands. It opens up new production and logistics possibilities, such as 1) rapid order fulfilment, 2) reduced manufacturing lead times, 3) postponement, 4) MC, and 5) high customer service level.

Rapid order fulfilment. The entire production system is set up to respond as soon as a garment is purchased in the shop. That individual sale generates a new order for a replacement item that is then communicated throughout the supply chain and inputs data into the production and transportation pipelines. If implemented in an effective logistics system, complete garment technology could make order fulfilment lead times shorter.

Reduced manufacturing lead times. Complete garment production has the advantage over traditional production methods of saving labour by reducing or eliminating time-consuming post-knit operations.

Postponement. With dyeing of the garments close to the POS, the risk of unsold products due to the wrong colour is lower. It could also work together with other techniques such as printing to accomplish an effective supply chain for knitted products.

Mass customisation. Knitting technology, combined with computer-based manufacturing and a new business system, makes it possible to customise each garment and offer the client "batch-one" manufacturing. MC is achieved with this technology due to production lots as small as single garments.

Customer service level. MC results in higher customer service levels, a reduction in lost sales, and a better quality product. Garments are seamless and incorporate features formerly available only in custom shops.

4.2 Article 2

4.2.1 Purpose and overview

Article 2 presents a design, production, and shop model for the ''Knit- on-Demand'' concept to show how complete garment knitting technology may be used for customised products. A business model with production equipment located in or adjacent to a retail 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 outlined. The method used is based on the Knit-on-Demand project, whose components are examined in detail with respect to processes, equipment, and lead times. A literature survey and discussions with suppliers of knitting machinery are included. Input data for the simulations were tested on the equipment for both design and production processes. The results of these tests provided information about lead times for all operations involved in manufacturing the product. That data formed the basis for the computer simulation that was modelled on customer demand.

Article 2 poses three research questions. RQ1: What is the customer demand fulfilment time for Design-in-Shop (i.e., self-designed) products in the Knit-on-Demand concept? RQ2: What is the efficiency of the knitting machines in the system? RQ3: What is the performance in production terms for the components of the Knit-on-Demand concept?

The model for Knit-on-Demand concept consists of four components and the values for those components. The Knit-on-Demand simulation model is illustrated in Figure 4.1.

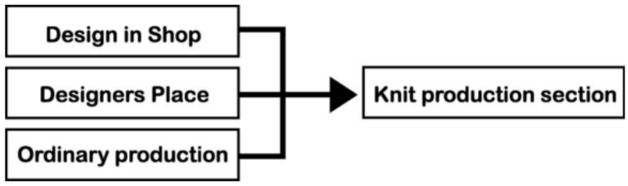

Figure 4.1. Components of the Knit-on-Demand concept.

a) Design-in-Shop is the area of the store where customers are invited to create their own garment, which is then manufactured on-site after the point-of-sale. b) Designer's Place functions as an ordinary shop, displaying ready-made garments that have been pre-produced on-site are available for purchase. c) Ordinary Production will stock the normal mass-produced inventory a knitting company would offer. d) In the Knit Production Section, an item configured in Design-in-Shop would be manufactured to a customer's specifications from yarn to complete garment in an interval of time that would depend on the material chosen, style, attachments, etc.

The data on customer behaviour is based on a study at a fashion store and was intended to build the Knit-on-Demand concept. In the simulation a customer enters the store every six minutes during the nine hours a day the store is open. Some customers will choose to customise a garment in the Design-in-Shop section, while others will buy a pre-produced garment in Designer Place. When any garment is bought in Designer's Place, a replenishment order is generated for the Knit Production Section and the item is quickly restocked. This resupply system also utilises the facilities of the Knit Production Section when there are no customisation orders pending.

Table 4.2. Design-in-Shop, preparation, and process lead times.

Process	Knitting	Washing		Drying	Steam	Sewing	Embroidery	Total process time	
Preparation	5		1	1	1	1	2.5	11.5	
Process time	55*	36	14	30	4	5	16.0	176.0	154.0
Total lead time	60	37	15	31	5	6	18.5	187.5	165.5

* Knitting time is triangular, i.e., distributed between 35 and 70 minutes with a mode (most likely value) of 55 minutes, due to varying knitting times for different models and allowance for thread breaks or errors.

The simulations were performed with two knitting machines in the Knit Production Section. Each simulation represented 200 hours and was repeated 15 times. All production lead times for the final simulation are displayed in Table 4.2. The process time for washing is either for cotton or wool garments. Total process time includes 30 minutes of co-design time. Production begins as the garment is sold and concludes when the customer receives the finished product.

The aim of the model was to give priority to the knitting machines in order to maintain their highest possible efficiency. Thus, if an operator is working with another process, he or she suspends it and begins operating the knitting machine if an order arrives. The model developed for the Knit-on-Demand concept was the discrete-event simulation type. We ran the simulation using AutoMod Version 11.2., a process for building models and simulating detailed design, materials handling, and manufacturing processes.

4.2.2 Principal findings

Article 2 described the benefits achieved by combining complete garment technology with MC in a business and production system for the Knit-on-Demand concept.

RQ1 asked: *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 demand fulfilment time would be from 120 and 301 minutes. A client could receive their customised item in 2 to 5 hours, although the lower figure would require a garment with minimal knitting production time and no embroidery. The calculation also assumes no waiting time and no queues in the shop.

RQ2 asked: *What is the efficiency (degree of utilisation) of the knitting machines in the system?* The result of the simulation shows that the efficiency of the knitting machines ranges from 79.1% to 90.0% (average 86.0%), a relatively high degree of utilisation. To improve the efficiency of the knitting machines, their set-up time must be minimised.

RQ3 asked: *What is the output in terms of manufactured garments for the different parts of the Knit-on-Demand concept*? The model and simulation resulted in an average of 367 garments produced by the system, and approximately 95 customer-designed garments sold in the Design-in-Shop part of the system.

The simulations show that productivity can be increased by shortening the process lead times. The pre-study shows that garment washing is a bottleneck in the production system. Water must be heated before the washing starts, which takes several minutes. A solution may be to pre-heat the water so that washing can begin as soon as the garment is placed in the machine.

We have endeavoured to show that a high fashion, customised garment may be designed, sold, and manufactured to order in two to five hours. Our findings agree with Choi and Powell (2005:6) that complete garment technology can be effectively employed in conjunction with MC to produce knitted garments. The Knit-on-Demand concept shows an alternative way for European knit fashion producers to shift from mass production to MC, rather than outsourcing their manufacturing to low-income countries.

Article 2 does not evaluate such financial aspects as the price of the garment or the profitability of the concept; it only analyses the design and production process. It focuses on problems of demand fulfilment time and suggests how they may be solved with a line of flat knitted fashion products. The present multiple-choice configuration system must be refined and expanded, and manufacturing processes have to be optimised. Products may be delivered quickly if there are no queues caused by many customers wanting to configure a self-designed product at the same time. Ideally, actual customer demand would be fulfilled on location. Where this is impossible, postal mail or express delivery may be the second best option, as is common practice in mail-order or Internet sales. Whether a delay of a few days or weeks would affect a customer's attitude towards the Knit-on-Demand concept has not been ascertained. A key success factor appears to be the quality of the shop personnel and the kind of customer service they provide. The financial aspects of the concept also need to be studied.

4.3 Article 3

4.3.1. Purpose and overview

Factory Boutique Shima has much in common with the retail concept Knit-on-Demand. The aim of Article 3 was to examine the way complete garment knitting technology has been used for MC of knitted products in Factory Boutique Shimas's design and production concept. Customisation rests on collaboration between a customer and a sales assistant. Several options are presented in the choice of style, material, size, trimmings, and colour. Swatches of fabric, fashion magazines, and yarn colour charts are available in the store to inspire customers to design a product. A selection of garments of various types and sizes is also on hand to support the client during the customisation process. The configuration or co-design phase is a process in which the customer navigates a series of options. The shop assistant writes or draws information on a customisation form that later becomes the basis for manufacturing the garment. When structures, patterns, colours, and all other options have been selected, a Computer-Assisted Design (CAD) system simulates the appearance of the completed garment. The manufacturing itself takes place after the client has purchased and paid for the product. Thus, nothing is produced until it has been ordered and paid for, and so the percentage of garments sold at full price (sell-through) is much higher than for a business model where garments are produced in advance of being sold (Mattila, 1999).

The investigation followed an inductive case study approach based on company visits and interviews with shop personnel. Quantitative data were collected and a Strengths–Weaknesses–Opportunities–Threats (SWOT) analysis performed using qualitative data to identify critical success factors in fashion retailing.

4.3.2 Principal findings

The SWOT analysis shown in Table 4.3 indicates some strengths, such as a high sell-through factor, no stockpiled inventory of ready-made garments, and a positive shopping experience for the customer. The Factory Boutique Shima concept suggests how their WholeGarment technology, as the process is called by that company, can be used for MC in the future. There are also business advantages in having a customer pay for a product before it is manufactured, and this may become one way for fashion retailing companies to compete for market share in the future. It is also very expensive to carry an inventory that may have gone out of fashion by the time it reaches the shop. The current system, in which one or two staff members devote their full attention to a customer during the co-design process, pleases customers. However, attending to one customer at a time is costly for the company, and so Factory Boutique Shima seeks to develop its co-design system to the point where customers do more of the customisation themselves.

Table 4.3. Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis.

Strengths	*Weaknesses*
Many years of knitting technology experience	Customers cannot take home the product with them
No inventory of ready-made garments	Risk of long queue of customer in the shop
No seasonal sales	Limited retailing experience
Positive shopping experience	Time consuming co-design process
High sell-through factor	Little reuse of customer information
Opportunities	*Threats*
To develop the co-design process	Limited design options available in WholeGarment
Large potential markets	Customers may be dissatisfied after delivery
Sell know-how to other retailers	Customers must wait to receive garment purchased
Internet sales	Time consuming co-design process
	Limited interest among consumers

The SWOT analysis suggests that Internet sales may present an opportunity for the future. With an efficient co-design system on a company's web page, a vast number of customers could be served at one time. Obtaining accurate customer measurements remains a challenge. One solution is to let customers take and enter their own measurements into the co-design system, as many companies already do. The analysis showed two main areas in which Factory Boutique Shima may improve their business concept: 1) adapting MC to products that can be manufactured with complete garment technology, and 2) developing the customisation concept.

The quantitative data in Table 4.4 indicates that the important fashion logistics factors for success (sell-through, control of lost sales, and stock turn) may be more positive for Factory Boutique Shima than they are for traditional fashion retailing companies. The data presented shows that the sell-through factor is from 90% to 100%, compared to an average sell-through of 65% to 70% in ordinary fashion retailing (Mattila, King and Ojala, 2002).

Table 4.4. Critical fashion logistics factors of success.

Success factors	*Ordinary fashion retailing*	*Factory Boutique Shima*
Sell-through	65% to 70%	90% to 100%
Lost sales	20%	Very few lost sales
Stock turn	4 times per year	Very high

The high sell-through percentage is due to the fact that nothing is produced that is not sold. Only customers dissatisfied with their garments will lower this percentage. Lost sales will be minimised because garments are generally customised, thereby increasing a client's likelihood of satisfaction.

A traditional retailing company that turns around its stock four times per year has a great deal of money tied up in inventory, thus negatively affecting its profitability. The stock turnaround for Factory Boutique Shima is much greater because only such raw materials as yarn and trim, but no ready-made garments, are kept in inventory. Complete garment technology also makes it possible to produce a garment faster than by conventional methods. It therefore lends itself to the future development of MC concepts of flat-knitted fashion products. Nevertheless, our analysis also showed limited interest in the market for the customisation of coarse-knitted garments. This may be due to the time-consuming, personnel-intensive co-design process, which, if improved, might encourage the spread of the MC concept.

4.4 Article 4

4.4.1 Purpose and overview

The purpose of Article 4 was to analyse and compare two different customisation systems. Both were developed by the Japanese supplier of knitting production equipment, Shima Seiki. One is a digital and the other a manual configuration system. The analysis is based on the Factory Boutique Shima store concept, which combines MC with knitting technology. As with the Knit-on-Demand project presented in this study, the store has ready-made garments, swatches of fabric, fashion magazines, and yarn colour charts to inspire the customer to design a product. A selection of garments of various types and sizes are also on display. In the process of creating the customised item, the client's measurements are taken by a shop assistant skilled in clothing design. The product line includes a variety of items made by the cut & sew, fully-fashioned, and complete garment manufacturing methods, with customisation options corresponding to each technology. After the manual customisation process has been completed, a customer is still free to cancel the order. If the sale is made, an order is generated and sent to the shop's production unit. A WholeGarment product is then made in one continuous operation on the knitting machine. Such a manufacturing process results in a seamless product with a more perfect fit and drape than is possible to achieve in the case of conventionally woven, cut, and sewn garments.

In contrast to the manual procedure just described, Shima Seiki has recently developed prototype co-design system to streamline the interaction between the customer and the company. This process, termed Ordermade WholeGarment, enables a client to do more of the customisation independently by means of a computerised system. The 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 details such as pockets and trims. This innovative software makes it possible to custom design a fashion product with much less help from a shop assistant than before.

Field work in Wakayama, Japan, was carried out in 2008 at the firm of Shima Seiki, supplier of knitting production equipment and inventor of the prototype co-design system Ordermade WholeGarment; and at the fashion company Factory Boutique Shima (Wajima Kohsan Ltd.). Information was also collected in 2010 from the Knit-on-Demand project and SOMconcept AB. Customisation processes were studied in two formats: Manual WholeGarment co-design and Ordermade WholeGarment. Both were evaluated and appropriated 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 provided additional understanding of two procedures. The data gathered from the three sources – Shima Seiki, Factory Boutique Shima, and SOMConcept – were used for the simulations. The results are presented in Article 4.

4.4.2 Principal findings

The first simulation compared customised garments made by the manual WholeGarment co-design process with products created using Ordermade WholeGarment co-design. Each simulation represented 200 hours and was repeated 15 times. For Manual WholeGarment, the result varied from 146 to 409 garments, depending on whether one, two, or three shop assistants were available to help with the co-design. Similarly, for Ordermade WholeGarment co-design, the number of customised garments ranged from 259 to 794, depending on the availability of one, two, or three computers for customer use.

The results of another simulation show the difference between the two co-design concepts. Five shop personnel were compared with 1000 configurators. Our intention was to show what happens if a configurator can be accessed through the Internet on a retailing company's website. Over the Internet, the system enables over 8000 products to be customised in a period of 200 hours, compared to less than 1000 products using manual co-design. The difference between a finite number of shop assistants and the almost unlimited capacity to configure orders on the Internet illustrates the vast possibilities the Internet offers for retailers.

There are two main benefits with a configurator system: 1) customers can do a considerable amount of customisation unaided, and 2) the customisation options in the co-design tool are pre-programmed to provide information to the knitting machine: when the customisation process is done, knitting can begin without the need for time-consuming programming. A configurator brings the entire process a step closer to mass-production efficiency, while maintaining all the distinctive features of customisation.

4.5 Article 5

4.5.1 Purpose and overview

The purpose of Article 5 was to describe the supply chain of the Knit-on-Demand concept. It examines the results of the customisation process, technology, systems, and logistics. A case study method and data from two cases were used. The purpose of the first case study was to map the Knit-on-Demand supply chain. A value-stream mapping technique was used to identify waste in the production chain. The study begins with a client entering the store and purchasing a garment, then follows the order back to the customer order decoupling point (CODP), where the order form the basis of a fully-fashioned garment with a cut & sew neck. The study traces the process until the garment is delivered to the customer. The purpose of the second case study, conducted during spring 2010, was to analyse the customisation of measurements for each purchase. These measurements were then compared with the standard size tables used in Sweden. The project ended in December 2010 due to the knitting capacity constraints of the manufacturer, Ivanhoe AB.

4.5.2 Principal findings

The original purpose of the Knit-on-Demand project was to test and evaluate complete garment technology. However, the investment required by the participating manufacturer was rejected as being too risky. We then considered using fully-fashioned or cut & sew production methods. Those technologies involved different set-ups and placement of the CODP in the production line. Cut & sew has the fastest order-to-delivery time, since panels can be knitted and kept in stock until a customer's order is received. The total value adding time in the production process was 126 minutes for a fully-fashioned garment with neck produced by cut & sew technique. Factoring in set-up and waiting, production lead time was 136.5 minutes.

However, when the cost of the garment is figured, the total time allotted to each operation is calculated using standard allowed minutes (SAM). This differs from actual lead time, depending on how much set-up time a process is allowed to have. In the knitting production step, the allowance is 100% due to downtime, set-up time, and problems that might occur in manufacturing a garment. Using SAM, the total lead time equalled 179.7 minutes.

Delivery time is one or two days to stores or directly to customers. The total lead time from customer order to delivery varies from one to three weeks. The target is to reduce throughput time in the factory to less than five days, thus decreasing total lead time to one week.

The analysis of the customisation process showed that most customers make minor size adjustments to garments, supporting the market need for MC knitwear.

Since this was the initiation of a new business concept, it was not known what the best design, production, or logistic solution would be. The method chosen by the research team, the production manager of the knitting company, and the retail owner offered the best trade-off between design flexibility, manufacturability, and aesthetics.

4.6 Results of appended articles

Table 4.5. Relationship between research questions and articles.

	RQ1	RQ1	RQ1	RQ1	RQ2
	Demand fulfilment time	*Sell-through*	*Lost sales*	*Stock turn*	*Co-design*
1	- risk with a slow logistics system - reduction of processes - time and material savings		- few lost sales		
2	- reduction of processes - risk of queues - ready-made product to customer in 3 to 5 hours	- customer involvement	- customer involvement	- no inventory of ready-made garments	- risk of queues - positive shopping experience
3	- reduction of processes - risk of queues - ready-made product to customer in 3 to 5 days	- high sell-through - customer involvement - customer satisfaction	- few lost sales - limited interest in the market concept - customer involvement - customer satisfaction	- high stock turn - no inventory of ready-made garments	- risk of queues - positive shopping experience - need for a better co-design system
4	- reduction of processes - risk of queues - knit programming before POS				- risk of queues - knit programming before POS - Internet sales
5	- risk of queues - ready-made product to customer in 1 to 3 weeks	- customer involvement - customer satisfaction	- few lost sales - limited interest in the market concept - customer involvement - customer satisfaction	- no inventory of ready-made garments	- risk of queues - positive shopping experience
Reconciled results					
	- reduction of processes - short time to customer - risk of queues - knit programming before POS	- high sell-through - customer satisfaction - customer involvement	- few lost sales - customer involvement - limited interest in the market concept	- high stock turn - no inventory of ready-made garments	- risk of queues - positive shopping experience - knit programming before POS - Internet sales

5. ANALYSIS AND DISCUSSION

This chapter analyses the appended articles within the frame of reference used in Chapter 2 in response to the research questions and the overall research objective: *How can complete garment knitting technology be applied in a retail concept for customised garments?*

5.1 Analysis of data

The analysis is based on the results of the articles presented in Chapter 4 (Table 4.5). The data are analysed by means of triangulation, value stream mapping, and cross-case synthesis.

5.1.1 Triangulation

RQ1 seeks to determine the fashion logistic effects of combining complete garment technology and MC. The effects considered are *demand fulfilment time, sell-through percentage, lost sales,* and *stock turn*. The triangulation of methods is used in the analysis to validate and compare the results of Articles 2, 3, and 5.

Table 5.1. Triangulation of methods in Research Question One (RQ1).

Art.	*Method*	*Demand fulfilment Time*	*Sell-through Percentage*	*Lost sales*	*Stock turn*
2	Simulation, action research	Ready-made product to customer in 3 to 5 hours	High sell-through		
3	Case study with interviews and observations	Ready-made product to customer in 3 to 10 days	High sell-through	Few lost sales	High stock turn
5	Case study, action research, interviews	Ready-made product to customer in 1 to 3 weeks	High sell-through	Few lost sales	High stock turn
Results		Corresponds	Corresponds	Corresponds	Corresponds

The triangulation results presented in Table 5.1 show that the fashion logistic performance factors in the articles correspond with one another. The reliability of the results in Article 2, however, may be open to discussion because it results from a simulation rather than an actual case with real customers, as in Articles 3 and 5.

5.1.2 Value stream mapping analysis

Value stream mapping analysis is used to assess the fashion logistics factor *demand fulfilment time* in RQ1 by comparing the complete garment knitting manufacturing process with fully-fashioned production. The processes in the value chain that are mapped are those from knitting the garment (or the panels of the garment) to the point where the components are sewn together. Production lead-time data for the analysis comes from Articles 2 and 5. Shima Seiki provided information about process time for complete garment knitting. The complete garment product was calculated as if it were knitted on a Shima Seiki model Mach2X machine. The fully-fashioned garment was knitted on a Stoll model CMS-311. Both products were based on a 12 gauge needle size. Preparation for the knitting process includes "reading in" the new knitting program and changing yarn cones. A finishing operation (steaming) was needed in both instances. Table 5.2 illustrates the production of a customised garment, including preparation and lead time from the initial knitting to the final sewing stage.

Table 5.2. Processes for fully fashion and complete garment manufacturing.

Fully-fashioned machine preparation and process lead times (in minutes) [a]							
Process	Knitting	Washing	Drying	Steaming	Cutting	Sewing	Total process time
Preparation	5,0	3,0	1,0	1,0	1,0	2.5	13.5
Process time	33,0	36,0	30,0	4,0	5,0	15.0	123.0
Total lead time	38,0	39,0	31,0	5,0	6,0	17.5	136.5
Complete garment machine preparation and process lead times (in minutes) [a]							
Process	Knitting	Washing	Drying	Steaming	Cutting	Sewing	Total process time
Preparation	5,0	3,0	1,0	1,0	1,0	1,0	12.0
Process time	36,0[b]	36,0	30,0	4,0	2,0	5,0	113.0
Total lead time	41,0	39,0	31,0	5,0	3,0	6,0	125.0

[a]Preparation and process data from the Knit-on-Demand project
[b]Process data from Shima Seiki

Value stream mapping shows that the total process time for fully-fashioned products is 123 minutes, compared to 113 minutes for articles produced on a complete garment knitting machine. Thus, the total lead time in each case is comparable. No other waste than time in the manufacturing process was measured. In this instance a cutting operation was still necessary for the complete garment example because the style required it. The process time for knitting was almost similar in both examples. However, sewing time in the complete garment process is less than for the fully-fashioned product since only labels needed to be sewn in. The latter garment is sewn (rather than knitted) together, with separately knitted trimmings and pockets added in a final sewing operation.

Depending on the design of the item, the total production time for a particular garment by any given method varies. The complete garment technique has some limitations in the structures that can be knitted. For example, Jacquard patterns can be difficult to produce, just as certain neck styles are hard to manufacture on a complete garment machine. However, if design, structure, and style are selected within the range of the possibilities that a complete garment machine offers, processing time can be reduced. Since pockets, trimmings, and other attachments can be incorporated directly into the knitted product with complete garment technique, additional operations required by cut & sew and fully-fashioned are eliminated.

In agreement with earlier research, as viewed in the Frame of Reference, we also found that complete garment knitting may reduce such manufacturing processes as cutting and sewing, but that knitting time remains the same, and in fact may even be longer than with conventional methods for same design (Choi & Powell, 2005:1; Hunter, 2004c:22). Many fashion garments require time-consuming additional sewing, a costly manual process, especially if the garment is made in a country like Sweden, where labour costs are high.

5.1.3 Cross-case synthesis

A cross-case synthesis was performed to analyse data and answer RQ2: *How does the co-design process function in the customisation of knitted fashion garments?* The case study method is applied in Articles 2, 3, 4, and 5. It consists of gathering data along with simulations, interviews, and observations. The synthesis was performed as illustrated in Table 5.3, using two alternatives for the customisation process: *manual* or *digital co-design*. Crucial factors for the interaction process between a customer and the company were identified as *risk of having to wait on line (queuing), efficiency, service, co-design tools, programming of the knitting machine after point-of-sale, and internet access*. The factors are rated according to whether they affect the co-design process positively, or negatively.

The analysis shows that the positive factors in the manual co-design alternative are a high level of service provided to the customer and no need for a co-design tool. On the negative side, however, are the risk of queues, a low efficiency level, no Internet ordering possibility, and the need for time-consuming programming of the knitting machine after the point-of-sale.

The positive aspects of the digital co-design process are efficiency in serving multiple customers at once, no knitting machine programming needed after point-of-sale, and the possibility of Internet ordering. Conversely, the customer is given no personal service and the retailer must invest in a sophisticated co-design tool (or several).

Table 5.3. Cross-case synthesis of data in analysis of Research Question Two (RQ 2).

	Positive aspects	
Article	*Manual co–design*	*Digital co-design*
2	High service level	
3	High service level No need for co-design tool	
4		Low risk of queues High efficiency No knitting machine programming required after POS Internet sales possible
5	High service level No need for co-design tool	
	Negative aspects	
Article	*Manual co–design,*	*Digital co-design*
2	Risk of queues Low efficiency Need for co-design tool Knitting machine programming required after POS No internet sales	
3	Risk of queues Low efficiency Knitting machine programming required after POS No Internet sales	
4		Low service level Co-design tool needed
5	Risk of queues Low efficiency Knitting machine programming required after POS Internet access; no	

5.2 Analysis of Research question 1

One purpose of this thesis was to bridge the gap and study the fashion logistics effects of combining complete garment knitting technology, fashion logistics and MC.

RQI: *What are the fashion logistic effects of combining complete garment technology and MC?*

The studied fashion logistics factors were: demand fulfilment time, sell-through percentage, lost sales and stock turn. Methods triangulation was used for the analysis of RQ1 to compare the results from Articles 2, 3 and 5. Value stream mapping was used for analysing the demand fulfilment time in RQ1.

5.2.1 Demand fulfilment time

Complete garment technology has been said to reduce manufacturing time and produce a knitted garment faster than by conventional methods (Legner, 2003:240; Choi, 2006:16). However, it is not clear that such knitting technology alone will expedite the production of a knitted garment. While reducing steps like cutting and sewing does result in a shorter production time, there are other factors to be considered, such as the number of production stages, value-added time in the different steps, and especially non-value added time between the processes. Only if production is optimised by restricting the number of non-value-added activities can the complete garment machine accelerate the manufacture of a garment.

Article 2 presented a business model for mass customised garments using complete garment production equipment located in the retail store. Customers were involved in the design process and garments were customised on-site to fulfil actual demand. A lead time simulation of the design and production stages showed that a customer could have a self-designed garment in 3 to 5 hours.

In Article 3 Factory Boutique Shima, whose operation used such complete garment technology for customisation, was analysed, although their manufacturing facility was located off the premises. By contrast to our simulation, they delivered a self-designed garment to a customer in 3 to 10 days after it was ordered, depending on production time and shipping destination. In the final Knit-on-Demand concept presented in Article 5 (based on cut & sew and fully-fashioned manufacturing techniques) the total lead time from customer order to delivery varied from 1 to 3 weeks.

Our study shows that the fastest fulfilment time is achieved when the production of the garment can start immediately after point-of-sale, as presented in Article 2, and this can be achieved if production equipment is in the store, at a nearby factory, or at another location linked by express delivery services (Article 5). According to Christopher and Peck (1997a:64) as viewed in the Frame of Reference, it is essential to keep time-to-market as short as possible in fulfilling customer demand for fashion garments. Even a demand fulfilment time of 3 weeks for customised garments is significantly shorter than the average for mass produced products, which in many cases can require a lead time of 40 weeks or more (Lowson, King & Hunter, 1999:48).

5.2.2 Sell-through percentage

In order to manufacture garments with a low production cost, the merchandise must be ordered long before the season starts (Mattila, King & Ojala, 2002:340). However, if one could decide what to manufacture closer to the point-of-sale, a premium might be charged for the garment (full-price selling). Articles 2, 3, and 5 shows that a knitted garment may be customised, manufactured to order, and delivered within 3 hours to 3 weeks. As shown in the simulation in Article 2, a delivery time of 3 hours can be achieved if everything is optimised in the customisation and manufacturing process, and there is no waiting time in-between. This would revolutionise garment manufacturing, just as same-day dry cleaning revolutionised a related sector of the overall business.

Data presented in the Factory Boutique Shima case shows that the sell-through factor, i.e., the percentage of product sold at full price, was between 90% and 100%, compared to the average sell-through of 65% to 70% in ordinary fashion retailing. This is an effect of MC more than the use of complete garment knitting machines. The high sell-through percentage indicated in Articles 3 and 5 can be attributed to the MC concept: production begins almost immediately after the point-of-sale. Although a high sell-through percentage is not directly visible in the simulation in Article 2, having a set-up that incorporates MC and expeditious manufacturing after a garment is sold may positively influence the sell-through.

5.2.3 Lost sales

This term refers to how many customers visit a store but do not purchase anything. It is a ratio that is difficult to measure because one cannot know whether a customer has any intention of buying (Mattila, 1999:112). Interviews with store personnel at Factory Boutique Shima during our case studies in Article 3 indicated that many of the people who visited the store to browse also began to customise a garment, and all those who started to design a product bought it in the end – a very positive outcome for the retailer.

Because the MC concept offers the opportunity to select from a wide array of options, most customers will be able to find something they like. However, where options are limited, as in the case of the configuration tool in Article 4, they may be dissatisfied, and lost sales will result. On the other hand, too many options can cause sensory overload or "mass confusion", with a lost sale as the unintended result (Piller et al., 2005). In the Knit-on-Demand project in Article 5, most customers who began to design a garment were pleased with the result because they obtained a garment that conformed to their exact measurements—something that would have been difficult to find in stores that only stocked mass-produced merchandise in standard sizes.

5.2.4 Stock turn

The ratio of inventory compared to sales is a measure of a company's stock turn. The purpose of this study was to analyse the fashion logistic effects of combining complete garment technology and MC, rather than calculating absolute values of stock turn.

The stock turn rate research question requires more data than is currently available in order to answer definitively. However, an indication of how complete garment knitting technology and MC will affect stock turn can be outlined. An interview conducted with the managing director of Factory Boutique Shima in conjunction with Article 3 indicated that the company's stock turn was "very high" in comparison to ordinary fashion retailing. (A more precise value was not given because of confidentiality issues.) In the Knit-on-Demand project in Article 5, however, the 60 garments sold over a period of 16 months at SOMconcept's store in Stockholm were too few to be able to calculate the stock turn rate.

A traditional retailer that turns over its stock four times annually has a great deal invested in inventory, which negatively affects its profitability. The stock turn for a profitable mass customisation company like Factory Boutique Shima can be much higher than the average figure cited above. The MC concept needs only relatively low-cost materials: (yarn, buttons, trimmings, and labels) to be kept in inventory; the shop has no ready-made garments in stock. Unlike other retail operations, everything the company produces has already been pre-sold.

Our findings indicate that it is difficult to measure the way complete garment knitting affects stock turnover. In the case of cut & sew and fully-fashioned production techniques, an inventory of semi-finished products often accumulates between the processes, as unfinished garments await cutting or sewing. This amounts to a great deal of product tied up in the manufacturing process. However, complete garment knitting, by making the entire product in one process, reduces inventory, eliminates much storage space, and affects stock turn positively.

Stock turn shows the efficiency of the total product flow. According to Lambert and Stock (1993), finished merchandise kept on the shelf is the most expensive form of inventory there is. The true annual cost of carrying inventory is at least 25% of its value (Lambert & Stock, 1993; Christopher & Gattorna, 2005:116). A high stock turn rate reduces a company's investment in inventory; minimises its need for warehouse space; lowers interest, insurance, and other related inventory costs; and results in a higher return on invested capital (Mattila, 1999:55).

Our study indicates that MC knitted products manufactured after point-of-sale have a positive impact on a company's stock turn rate, compared with conventional marketing of mass produced-products.

5.2.5 Findings

The combination of complete garment technology and MC does not affect fashion logistics factors more positively then if another knit manufacturing technique were employed. Mass-customised garments produced on flat knitting machines shorten demand fulfilment time, increase sell-through percentage, reduce lost sales, and improve stock turnover. A combination of elements is responsible for achieving this effect. The MC concept allows a garment to be sold before it is manufactured, by allowing the customer to configure the product. As Hunter, (2004c:21-22) and Choi and Powell, (2005:1-6) also conclude, complete garment production reduces lead times.

More problematic is the issue of garment design. If the style of a product is within the range of manufacturing possibilities on a complete garment machine, the advantages of technology can be fully exploited and manufacturing lead time can be reduced to hours rather than days or weeks. A demand fulfilment time of three hours gives advantage for a retailer. It may also be possible to achieve short turnaround times with the cut & sew and fully-fashioned manufacturing techniques, but that would require the integration of the manual processes of cutting and sewing with knitting machine operations in a highly efficient way.

Although it is possible that a customer may be dissatisfied with something they pre-purchase, experience has shown that it was unusual for a client to return a customised garment. According to store personnel at Factory Boutique Shima, such an occurrence was generally caused by a misunderstanding in the co-design process. (For example, a customer wanted a stripe on the sleeve and this information was not accurately noted.)

Customers who have a hand in the design process tend to anticipate the outcome positively, take ownership of the product in advance, and are less likely to return their purchase, even if it was bought on impulse. A customised garment that is designed, manufactured, and delivered in 3 to 5 hours, and that fits perfectly, will be welcomed by most customers, whose satisfaction will result in increased sales. Thus, the concept of MC and the technology of flat knitting may be combined to achieve fashion logistic possibilities far beyond what retailers could offer customers in the past.

5.3 Analysis of Research question 2

In MC of knitted products the co-design or interaction process between the company and the customer is an important process. One purpose of this thesis was to study this process. The co-design process in the MC of knitted fashion garments may function either in manual or digital mode. A cross-case analysis was done to analyse data in Articles 2, 3, 4 and 5.

RQ2: *How does the co-design process function in the customisation of knitted fashion garments?*

5.3.1 Manual co-design

Manual co-design is an interaction between the client and a shop assistant in designing a garment without the aid of a digital tool. This type of co-design offers certain advantages, as has been shown in the case study of Factory Boutique Shima, which uses a manual procedure described in Article 3. In this collaborative endeavour, the client is given the full attention of one or two shop assistants. Body measurements are taken to assure a perfect fit, and colours, patterns, structures, and attachments are selected in consultation with the store personnel – an interaction that customers perceived as positive. Lampel and Mintzberg (1996:26) call this “tailored customisation”: the company shows the buyer a prototype and then modifies it to the customer’s preferences. A similar dialogue with the customer is termed the “collaborative” approach by Gilmore and Pine (1997:92).

The simulations presented in Articles 2 and 4 indicate the problem inherent in manual co-design is the limited number of customers who can be served at any one time. Perhaps this can be remedied by scheduling appointments, as people are in the habit of doing with their hairdresser or tailor. If the co-design process can be planned in advance, client frustration while waiting to be served can be minimised.

The Knit-on-Demand concept uses a manual co-design process in which the customer is allowed to change four of the garments parameters: model, fit, colour, and details (Article

5). Larsson, who has studied this approach, found that store personnel and customers both wished they had a tool that visualised the customer's choices (2011).

Huffman and Kahn (1998:492), concluded that customers prefer a limited number of *attribute-based* options that are presented by a shop assistant, rather than an *alternative-based* system in which customers are confronted with numerous possibilities to choose from on their own. Both in Factory Boutique Shima and in the Knit-on-Demand case, a manual co-design process was used with an attribute-based selection of alternatives along with the guidance of store personnel.

5.3.2 Digital co-design

Digital co-design incorporates a digital tool in the interaction between the client and a shop assistant in designing a garment. The interface between the company and the customer is a crucial process in MC. Customer satisfaction depends on obtaining accurate body measurements and getting the computer screen to display the true colour of the finished garment.

The MC of complete knitted garments is made more efficient through the use of a co-design configurator. Analysis of the manual and digital customisation concepts and the simulations in Article 4 show the strength of such a tool, which is IT-based (Bourke, 2000; Franke & Piller, 2003:581; Weston, 1997:73). More customers can be served via computer co-design than by a manual process, reducing the number of store personnel involved and potentially lowering costs. In addition, a configuration tool enables customisation over the Internet, allowing a retailer to engage in e-marketing.

The digital system examined in Article 4 offered the following advantages:

1) Most customisation can be done by a client working unaided with a configurator
2) Limited programming of a knitting machine is required after point-of-sale
3) A configuration tool makes retailing of customised garments on-line possible

The drawbacks include obtaining a client's measurements and the limited number of design options that current knitting machine technology offers. The Swedish company Tailor Store shows customers how to take their measurements on their website. Offering an increased selection of styles, colours, and materials might encourage more customers to purchase customised garments on-line.

5.3.3 Findings

The co-design process can take place at a shop, through an on-line configurator, or using a combination of both concepts, as described by Reichwald, Piller and Mueller (2004). Thus, a customer can be personally guided through the customisation by a shop assistant, a process the authors find advantageous because of the reassuring direct interaction it allows. The same customer can later access an online tool to place a reorder. Such manual co-design is preferred by many customers for the personal service it affords, especially for clothing in the higher price range. Stores that already have an established staff may consider adopting such an MC concept if they wish to expand their business strategy.

Manual co-design does not require a great investment, and do not require a digital configuration tool. Such an expense may be too much for a small company, as we found in the Knit-on-Demand project (Article 5). Larsson (2011) concluded that most customers were not concerned about lead-times or price. On the other hand, offering to deliver a customised garment in 3 to 5 hours (see Article 2) might it be a considerable advantage for a retailer.

A great benefit of the digital co-design system was the pre-programmed options in the configurator. These eliminated or greatly reduced manual reprogramming of the knitting machine, thereby expediting the manufacture and delivery of the finished product. This corresponds to that all known mass customisers use systems that are to some extent IT-based as mentioned in the Frame of Reference of this thesis.

The future of mass customisation of knitted garments looks bright for co-design systems of the kind we have considered. Perhaps shops like Factory Boutique Shima or Knit-on-Demand will one day offer their clients the opportunity to design a product that is knitted in the shop and delivered to them within hours. We may also see collaborations between retailers with an insight into fashion trends and efficient knitwear manufacturers for the development and production of co-designed products. Soon the technology will be available that can facilitate the growth of stores devoted to the MC of fashion products with a minimum of help from shop staff.

5.4 Overall research objective

Overall research objective: *How can complete garment knitting technology be applied in a retail concept for customised garments?*

A retail store with knitting machines on the premises or at a near-by location (Articles 2 and 3) can realise such advantages as 1) high sell-through percentage, 2) short lead times, 3) few lost sales, and 4) high stock turn. Much of the clothing we wear today is made in Asia in low-cost manufacturing facilities, resulting in fierce industry competition. One way to stimulate profitability may be to offer prospective customers something new by involving them in the design process. MC may be one answer. A customised garment can be created on-screen or on paper, and if the customer finds the result satisfactory and the garment is bought, production can begin immediately. The customer may even be able to watch the entire process from yarn to ready-made garment. Such a store visit will be a memorable experience, unlike conventional shopping.

An MC concept can also launched with production facilities off-site, as in the Knit-on-Demand project, where the custom-made garment is shipped to the customer by express mail. This kind of collaboration between a retailer and a manufacturer is seen in the SOMconcept AB and Ivanhoe AB partnership described earlier.

The Knit-on-Demand project in Article 5 involved similar fashion logistics factors as the case study in Article 3 and the simulation in Article 2. The shortest lead time in the simulation was 3 hours from design to delivery of a ready-made garment. Factory Boutique Shima delivered a garment in 3 to 10 days, compared to 1 to 3 weeks in the Knit-on-Demand project. Three weeks is still a relatively short lead time compared to what many mass producers can achieve. The result in Article 5 indicated a high sell-through percentage, few lost sales, and a high stock turn, as in Articles 2 and 3.

For complete garment technology, programming and control of the knitting machine is a bottleneck and has been since the technology was launched. Complicated, time-consuming programming is required to manufacture garments ready-made in the machine, and although this has improved, there is still much to do. There are advantages in having pre-programmed design options in the complete garment knitting machines before the customer starts designing the garment. Pre-programming will reduce processes once the product is bought and will provide the customer with faster delivery. However, for customers to be satisfied, it is necessary that a wide variety of design alternatives be made available in the configurator (Article 4). A digital design tool on the Internet can be linked to the possibility of instant chat or telephone support for help with questions about quality, measurements, etc. Finally, complete garment technology in combination with MC may require less retail showroom space for finished goods, resulting in savings in areas with high rents.

5.5 Assessment of the research

5.5.1 Relevance

One of the criteria used to assess research is its relevance, i.e., its contribution to increased knowledge. It should be of value to the scientific community, the profession, and to the public (Gummesson, 2000:187). The relevance of this dissertation to the fashion industry and to the research community (as applied research) is based on the following:

It is currently of great interest to anticipate what will happen if complete garment technology, MC, and fashion logistics are combined. An understanding of these three elements working in combination brings new knowledge to the fashion business. Such insight can be used by textile manufacturers, particularly knitting producers and fashion retailers, who are planning to incorporate MC into their operation.

The garment industry has always had problems with long lead times. The consequence of having to sell “stale” fashions at reduced prices has a negative impact on economic performance (Mattila, 1999).

As retail MC concepts for knitted products with short lead times have not been previously studied, this study contributes new knowledge to fashion management science by showing how complete garment knitting technology can be implemented in a MC concept. MC allows a product to be sold before its production begins. The examples in this thesis are models of new business concepts for knitwear. Complete garment knitting is an example of rational technological development in textile manufacturing. These strategies may be extended to other areas of textile production, such as printing, dying, and weaving, and this study may be suggestive of innovations combining MC with these areas.

The co-design process is essential in order to succeed in MC. We have evaluated this process for flat knitted products and indicated how it may be further implemented following the example of Shima Seiki, who developed the first system that connected knitting machines with a MC configurator. The effects of this are relevant to study, and can provide a basis for further improvements in the area.

5.5.2 Validity and Reliability

Validity indicates that research measures the issues intended and not something else (Gummesson, 2000:187). A study's reliability means that, using the methods described, the research can be repeated with the same results by another researcher (Gummesson, 2000:185; Yin, 2009:40). To increase validity and to answer to the primary aim of this thesis, several types of data were collected using different methods: case studies, simulations, interviews, and participant observation.

The validity of the research may be examined from the perspective of the two main methods used: simulations and case studies. Article 2 was a simulation of a retail store using a specific production concept, and Article 4 presented a simulation in which manual and digital co-design were compared. The validation of a simulation model is complex (Banks et al., 2004:354-357). Validation is not an isolated set of procedures, but an integral part of model development. Banks and Carson et al, offer several suggestions for validation of the model development process, and three of those were used for the simulations in this thesis:

1) Have the model checked by someone other than its developer. The model was checked by participants in the Knit-on-Demand research project who were independent of those who developed the model in the simulation program.

2) If the model is animated, verify that what is seen imitates the real system. In Article 2 the model was animated and proved to be similar to the real system.

3) Closely examine the model output under a variety of settings and judge if it is reasonable. The input data for the simulation were based on information from machine equipment companies, Factory Boutique Shima, and our own trials at the Swedish School of Textiles (Nilsson & Olofsson, 2006). Input data and the model output were evaluated by experts in the knitting business who concluded that they were reasonable.

Yin (2004:40-44) reported four common tests to use to establish the relevant quality of case studies:

1) Construct validity: identify correct measures for the concepts being studied by using multiple sources of evidence and having key informants review the case studies. The findings in this dissertation come from several studies with more than one source of evidence. Key informants from Shima Seiki, SOMconcept AB and Ivanhoe AB have reviewed the results from the case studies and found them valid.

2) Internal validity: seek to establish a causal relationship in which some conditions lead to others. In examining case studies, we have sought to explain how and why event *x* led to event *y*. The results of the value stream mapping case study in Article 5 come from a real-life manufacturing process. If the same garment is bought again, it can be manufactured with the same result. In Article 3 the co-design process was studied in the store, garments were customised and produced, and interviews conducted. Those co-design processes can be replicated if the same garments are customised again, so the results can be counted as reliable.

3) External validity: determine whether findings are generalisable to other cases in the same area of research by testing them in a second or third case. External validity in this thesis has been sought by testing the research questions in five articles containing different case studies and simulations.

4) Reliability: it should be possible to repeat the study following the methodology used and obtain the same results. The aim of reliability in research is to avoid bias and errors in the study (Gummesson, 2000:185). Several data sources and research methods incorporating simulations and case studies have been used to support the reliability of the results. The Factory Boutique Shima and Knit-on-Demand case studies produced data from real MC retail environments, making the findings more accurate than the simulations in the articles alone. In the Factory Boutique Shima case study, one person acted as a customer in the co-design process, and data were gathered by participant observation. If there had been the opportunity, more accurate data might have been collected by observing real customers.

The theoretical basis for the study presented in this thesis has been described in the first two chapters. The five articles on which the research is founded have been published in peer-reviewed scientific journals.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

A principal task of case study research is the increase of knowledge from the perspective of the scientific community (Gummesson, 2000:187). Little research has been done in the area of complete garment technology in conjunction with MC and fashion logistics. Most of what has been studied previously has focused on either MC or logistics separately.

The intention of this thesis is to present a number of case studies and simulations examining various MC retail concepts in combination with complete garment technique in order to evaluate the performance of key co-design and fashion logistics factors. The idea pursued with regard to fashion logistics was that customer service levels and sell-through percentages would increase and lost sales would decrease compared to ordinary fashion retailing. A strategy for mass customised knitted garments using a manual co-design process was developed in collaboration with SOMconcept AB and Ivanhoe AB and tested in the SOMconcept store in Stockholm. Manual co-design was also examined in a case study at Factory Boutique Shima in Japan, where an analysis between this system and Shima Seiki's Ordermade system was conducted. The main contribution of this research is a description of two kinds of MC retail concepts for customised fashion products manufactured by complete garment knitting technology and other knitting techniques.

MC of knitted products requires specialised production facilities located in the retail store, at a near-by facility, or at a remote location linked by good shipping facilities. If production takes place in the store, it is possible to customise and deliver a garment to the customer in 3 to 5 hours. If the garment is manufactured at another location, the total lead time from customer order to delivery can range from 1 to 3 weeks. Both systems operate within a relatively short lead time compared with mass-produced products sold at ordinary fashion retailers. The retail performance ratios as sell-through percentage, lost sales, and stock-turnover were affected positively, confirming that lead time is an important factor for success in the fashion industry. In the MC process itself, two kinds of interactions are feasible between the company and the customer: manual or digital co-design. A manual process in which the customer is actively involved in the design, but guided by a shop assistant, is the basis of concepts like Knit-on-Demand and Factory Boutique Shima. Manual co-design does not require advanced technical equipment, as all the information can be entered by hand onto a customisation form that is then sent to the production department. However, manual co-design is labour intensive, since a shop assistant can only serve one client at a time. It also is only applicable to brick-and-mortar stores and not transferable to the Internet.

Digital co-design, on the other hand, encourages customers to do the customisation on their own, without the aid of sales personnel. If a store has an ample number of configurators, there will be little risk of queues. Moreover, this technique is ideal for the Internet. The problem of taking body measurements, however, awaits a satisfactory solution and still requires help from shop employees. If customers can be encouraged to this by themselves, as some on-line retailers like Brooks Brothers and Land's End in the US have shown, mass-customised knitted garments could be widely sold on the Internet, thereby reaching vast numbers of customers. Tailor Store is another example of an Internet MC shirt retailer whose customers take their own measurements and enter them on the company's web page. Complete garment technology is also more economical for the manufacturer: there is no material cut-loss, and a minimum of costly post-knitting processes are needed. Disadvantages to date have included limited design options and the need for custom programming of the knitting machine. (In the digital co-design system studied in this thesis, the design options were pre-programmed in the configurator and so a customised garment could be knitted without delay).

Mass customised garments are especially suited for people whose bodies do not fit standard sizes or who wish to create a garment with a unique design (Larsson, 2011). Providing a purchaser the satisfaction of a perfect fit, an original creation, rapid customisation, and the opportunity to try one's hand at fashion design opens up many new retail possibilities.

6.2 Suggestions for further research

The focus of this research was to explore new avenues in combining complete garment knitting technology with MC and fashion logistics. However, there are many issues requiring further research in these areas.

First, the case study presented in Articles 3 and 5 can be extended by more in-depth interviews with customers to solicit their thoughts on being involved in designing a garment. Did they find it of value and would they like to purchase clothing this way in the future? It would also be worthwhile to learn whether they preferred manual or digital co-design. In Article 4 we compared co-design in a simulation, and this can be extended to a real shop environment. Customers can first customise one garment with the digital tool and another with the help of a shop assistant, and then compare the two experiences.

Additional case studies could examine the effects of combining MC with other textile manufacturing techniques, such as digital printing or knitted hosiery. Digital printing allows postponing the customisation of a garment by adding a design of the customer's choice after it is sold. Factors to be examined here would be lead times, inventory, and the co-design process. An industry-wide problem awaiting solution is how to obtain accurate body measurements more simply than measuring the customer in the store. Finally, there are still long lead times in the sourcing and production of knitted products in ordinary fashion retailing. It should be possible to build a supply chain with complete garment knitting machines that respond faster to fashion trends even if MC is not involved. Thus, the concepts we have examined in a restricted context may bear greater fruit if integrated into other areas of fashion supply and retailing.

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