KNIT ON DEMAND – SIMULATION OF AN AGILE PRODUCTION AND SHOP MODEL FOR FASHION PRODUCTS

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ABSTRACT

In fashion business customer demand is changing due to fashion trends and new designs. Time from customer demand to customer demand fulfillment is essential for company's ability to compete in the fashion retailing business. During the last 20 years there has been a dramatic technical development in the production of flat knitted garments. This has made it possible to rationalize design and production in a way that it's possible to make a knitted garment ready made directly in the knitting machine, with a minimum of after coming processes. Objective of this paper is to present a design, production and shop model for the "Knit on Demand" concept and show of how this new production technology could be implemented in a fast fashion logistics system. A business model with the knitting machines and production equipment located in the store is presented. The customer takes part in the design process and garments are customized to fulfill actual demand. Aim is to present a lead time simulation of design- and production processes involved in the shop concept. Result is a model with starting point in customer demand and final point in demand fulfillment. Simulation shows that the customer could have an own designed garment in 2-5 hours. Simulation of the developed shop model is done in the software tool AutoMod. Methodology for this paper is based on a research project of the Knit on demand concept idea at the University College of Borås, literature research and discussions with suppliers of knitting production equipment.

1. INTRODUCTION

One of the problems in the fashion retailing business is long lead times often depending of the fact that sourcing and production are done up-front often in low cost countries in Asia. It is important that the production and logistics system in fashion, with short life cycle products is agile and respond quickly to changes in customer demand (Bruce *et al*., 2004). If the production and logistics system respond to slow to the actual demand there is an impending risk that when the customer wants to buy a specific high fashion garment the shelf in the shop is empty or the product is out of fashion. The difference between the "logistics pipeline" and the customers order cycle time called the "lead-time gap" is a problem, often filled with forecast-based inventory. (Christopher *et al*., 2004). There is also a huge risk for a high level of unsold goods that have to be sold at reduced price. This in a business where the demand is changing day-by-day and a low time to market is essential for the company's ability to compete. Christopher and Peck state that one dimension of time based consumption is: Time to market**,** i.e. how long it takes the business to recognize a market opportunity, to translate this into a product or service, and to bring it to the market (Christopher and Peck 1997). Time to market could be divided in to value added time and non-value added time. Value added time is time when some value is added to the product, for example knitting finishing or

sewing of a garment. Non-value added time is, for example, waiting time between value added processes. It is of high interest to keep Time to market as low as possible to be able to fulfill actual customer demand (Christopher 2000). The best should be to sell the garment first and then start the production after the point of sales. This would reduce risk for unsold goods that has to be sold out to reduced price. The technical development over the last 20 years has opened up new possibilities, when it comes to the production of knitted fashion products. It is now possible to make almost complete garments directly in the knitting machine without post knitting processes such as cutting an sewing (Choi and Powell 2005). This enables the time "from yarn to ready-made garment" to be shortened considerably, by the fact that not only the post-knitting processes to a high degree are eliminated; several non-value-added activities are also eliminated. These non-value-added activities as waiting time or time for transportation between the cutting and sewing processes are reduced. This technology implemented and adjusted to the production- and business system in a company could reduce lead- times dramatically and facilitate a quick agile response to customer demand.

Mass customization is one future way for the fashion- and apparel industry but garment fit and colour selection has been some of the limitations. (Fralix 2003). Knit on demand is a business model with the knitting machines and other production equipment located in the shop, or near by. With this model the customer takes an active part in the design process and the garment is customized to fulfill actual demand. Design is made by the customer in a "multiple choice design system" with several options for the customers when it comes to styles, materials, sizes, attachments and colours (Peterson 2006). Agility in its most extreme case could be a concept where the customer places an order and the manufacturing takes place after the moment of point of sales. With this approach there will be nothing produced that isn't sold and the sell-through factor (the percentage of the garment sold to full price) will be much higher than using a concept where the garment is produced ahead of the point of sales (Mattila 1999). The idea with this concept is customization of consumer products and that the customer wants to be a part of the developing- and design process of the product. The complete garment technology combined with a demand driven logistic system could be a platform for a new concept in the business of knitted garments. In the concepts of logistics and Supply Chain Management (SCM) also the philosophy of quick response is established in the fashion- and apparel industry (Lowson *et al.,* 1999).

The complete garment technology incorporated in an agile, demand chain strategy could open up new business opportunities compared to traditional retailing of flat knitted products. The agile approach focus on business with high variety and low volume, in environments characterized of low predictability (Christopher 2000). To get economy in the Knit on Demand concept it's crucial to keep personnel and equipment occupied to maintain high cost efficiency in the system. One of the disadvantages with this system is that it is a high possibility that customers not will come to the shop in equal amounts and intervals; there will be, to few or to many customers at the same time in the shop. Few customers will mean that personnel and equipment are not occupied and only cost money. Too many customers at the same time will cause queues in the system, resulting in delay of deliveries. To overcome and deal with these problems the business model must take these scenarios into consideration. With this background the Knit on Demand concept consists of three different logistic parts, namely: Design in Shop, Designers' Place and Ordinary production (Peterson 2006). Design in Shop is the concept where customers are making their own design and the garment is manufactured after point of sales. Designers' Place function as an ordinary shop with garments that is pre-produced. The idea with Designers' place is that every bye of a garment will generate a production order to the knit production section that, as soon as possible, will manufacture the garment and deliver it to designers' place section. Ordinary production will

be the normal production of products for a knitting company. With these three scenarios of production there could be a higher degree of efficiency in the system and when there are no customers for Design in Shop the other parts could maintain the production in the knit production section. The purpose of this paper is to present a design, production and shop model for the Knit on Demand concept. The aim is also to present a lead time simulation of design- and production processes involved in the shop concept. After development and estimation of preparation- and process lead times of the Knit on Demand concept a study of the performance of the concept was needed.

2. METHOD AND RESEARCH QUESTIONS

The overall aim of the research is to develop and describe the Knit on Demand concept and to develop a model for simulation of the concept and to present the result of a first computer simulation of the concept performance. The aim is also to consider how well the Knit on Demand business and production system performs when it comes to customer demand fulfillment time, production time and efficiency of the knitting machines in the system. A model of the Knit on Demand business concept has been presented in the paper "Design in Shop – Business and production methods in the demand chain of knitted products (Peterson 2006). The research described here is an extension and refinement of this paper and a system state variables model of the Knit on Demand concept are developed. A collection of variables are defined to describe the system. A computer simulation of the model is presented and the result shows how the different parts of the Knit on Demand business concept perform when it comes to customer demand fulfillment lead times and efficiency of the knitting machines in the system. The method used in the research is based on the Knit on Demand concept idea where the different parts are described and studied in detail when it comes to processes, equipment, and lead times.

The research is based on literature research and discussions with suppliers of knitting production equipment. In-data for the simulations was studied in a student research project for both design- and production processes. Each production- and preparation process was studied and tested in practice separately and process lead time was estimated and set. The result of this work was used as in-data in the computer simulation. A model with focus in customer demand was developed and used in a computer simulation of the concept.

Following research questions was formulated.

(1) What is customer demand fulfillment time for Design in Shop - own design products in the Knit on demand concept?
(2) What is the efficiency of the knitting machines in the system?
(3) What is the performance in produced products for the different parts of the knit on demand concept?

3. COMPLETE GARMENT – A TECHNOLOGY FOR FAST FASHION

The technology of today makes it possible to manufacture products of a wide variation of materials, models, structures and patterns in the complete garment technology. The cost saving benefits with no material cut-loss and a minimum of post-knitting processes make this technology one of the future production methods in the supply chain for knitted garments (Choi and Powell 2005). This technique with flat knitting machines producing complete garments has been on the market since 1995, and companies such as Shima Seiki from Japan and Stoll from Germany have been the two leading machine manufacturing companies of this

technology (Hunter 2004). Benefits with complete garment production are savings of material as cut-loss and savings of expensive and labour intensive post-knitting processes, such as cutting and sewing. Details of the new knitting technology can be found in (Mowbray 2002). But real benefits of this new production method are not only savings in material and labour in the manufacturing processes of the garments that are produced. To be successful and gain all benefits that are possible, it is necessary to adapt the production system and the whole supply chain to a new concept, from producer to customer. It is not enough to just buy a new knitting machine and put it in the same production and business system as before. The complete garment technology opens up new production and logistics possibilities such as order fulfilment lead-times, mass customisation, customer service level and postponement. As shown in figure 1 the labour intensive and time consuming cut and sew process are eliminated with complete garment production. Depending on style of the garment some additional cutting and sewing of labels, trimmings can still be necessary.

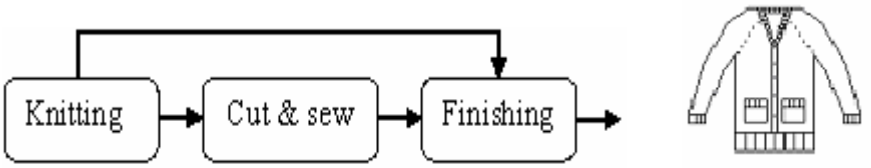
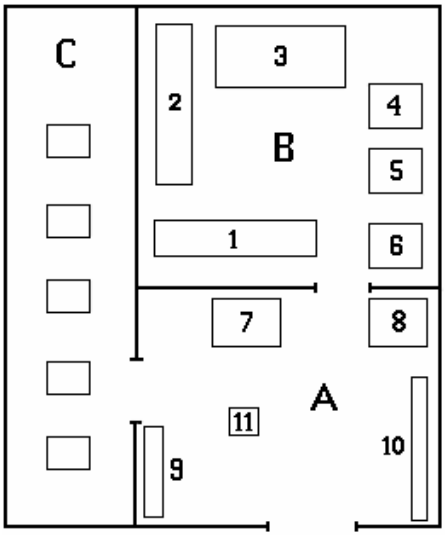


Figure 1: Production process of complete garment concept

4. KNIT ON DEMAND

4.1 Knit on Demand – The concept

Design in Shop is a business concept based of the manufacturing technology of complete garment production. The customer will be involved in the design process of the garment and could choose between alternatives of style, material, colour, structure and size. There is also an option to have embroidery on the garment. The layout of Design in Shop is shown in figure 2 and a total space of approximately 100-120 m^2 will be required. The space will be divided in three sections: A. Design in Shop, B. Knit production section and C. Designers Place. In the Design in Shop section the customer will come in to the shop and there he/she will have the possibility to look at sample garments that can be produced in the shop. Here will also be fashion magazines, swatches of structures, colour charts and samples of sizes available for the customers. If a person wants to design his/her own garment they will be guided by a shop assistant, skilled in design, to a customized and personal design of the garment. This will not be a free design in the sense that the customer can create a new product without limitations of style, colour, structure and size. Design of the garment will be done in a design system where the customer will be presented to a multiple choice system and will in several stages get the opportunity to choose different options of design for the garment. There will be choices of style, material, structure, colour, size, and attachments for the customer. When this multiple-choice design is made, a print out is done, and the customer can see the result of the work. There will also be possible to take a photograph of the customer and virtually dress the person in the new design. After this procedure the customer can decide if the garment will be bought. If the answer is yes it will generate an order to the production unit of the shop. In the knit production section the garment will be manufactured from yarn to complete garment ready to wear for the customer. The manufacturing consists of several processes, how many depends of material composition, style, attachments *et c*. Designers' Place is a section of the shop that works as an ordinary shop where customers could bye already made pre-designed garments.



Layout
A. Design in Shop
B. Knit production section
C. Designers Place

Equipment
1. Knitting machine
2. Knitting machine
3. Steaming table
4. Washing machine
5. Tumble dryer
6. Sewing machine
7. Knitting CAD
8. Embroidery machine
9. Garment samples
10. Yarn cones
11. Camera

Figure 2: Knit on Demand, layout and equipment

4.2 Design done by the customer

The design in shop gives the possibility for the customer to design his/her own sweater and also customize it after his/her requirements and needs. The way from the customer entering the shop until the customer's personally designed garment is manufactured, sold and delivered is shown in the following steps: 1.Entering the store 2.Browsing at the store 3.Design in the multiple choice design system 3.Point of sales 4.Production 5. Pay at the counter 6. Delivery. The idea is that the customer comes in to the shop and looks at sample garments, yarn and swatches that are displayed. After decision that an own garment will be designed, the shop personal, a design technician, will guide the customer through the design process. This process is a multiple-choice system where the customer gets options in several stages from the beginning to the end of the design process. The multiple-choice system present several options and at the end a complete designed garment are shown to the customer. The design options in the multiple choice system will be pre- programmed in the knit CAD system in a modular system where the options can be combined together to a garment that can be transferred to a knit program for the machine to knit the actual product. A photo print with the customer dressed in the new designed garment will be available.

4.3 Manufacturing of the product

The manufacturing of the products takes place in the back room of the shop, well in sight for the customer. One aim with this concept is that the customers can be a part of the whole process from idea and design to the manufacturing of the product. After the design process and point of sales the manufacturing of the product starts as quick as possible. It could be a queue for the production facilities depending on how many customer design products that are ahead in the system. Process time for design is estimated to 30 min. The manufacturing of the garment consist of knitting, washing, tumble-drying, steaming and some additional sewing and embroidery. Preparation or set up time for each process are estimated to be between 1 to 5 minutes depending on the art of preparation needed. For the knitting process set up time includes to read in a the new knitting program, take off yarn cones from the last knitted garment and set up yarns for the next product to be knitted. The facts about time for each process are based on information from machine manufacturers and tests done in a research project at School of Textiles, Borås, Sweden. Total theoretical time for the design and manufacturing processes for a customer design garment will in this case be in the range of 166 to 188 minutes (Nilsson and Olofsson 2006).

5. THE SIMULATION MODEL

5.1 Simulation modeling method

A model could be explained as an artificial representation of an actual system. A model should also contain details, without more details then necessary to answer the questions meant to be known. The simulation method used in this paper is the process- interaction method with the basic concept to emulate the flow of an object through the system. The object moves in the system until it is delayed, enters an activity or is finished from the system. When the object is stopped time is advanced to the next movement. This flow, describes in sequence all of the processes, waiting times or other states that the object can attain in the system. Each process and event in the model is simulated (Banks 2000). The simulation model used in this paper is of the type discrete-event simulation model. This means that the model represents the components of a system and their interactions. Discrete-event models are time-based with the results based on the interactions of system components. The model for the Knit on Demand concept consists of the different components in the system and the values for these components. The Knit on Demand simulation model used in the simulations runs consists of three parts A. Design in Shop, B. Knit production section, C. Designers Place as illustrated in Figure 2. The simulations were performed with two knitting machines in the knit production section. Each simulation was 200 hours and repeated 15 times. All production lead times for the final simulation are displayed in Table 1. Starting point for the simulation is at the point of sales when the customer is ordering the product and the final point is when the customer has got the produced garment and paid for it. The aim of the model is to give priority to the knitting machines to maintain as high efficiency of the knitting machines as possible.

5.2 AutoMod simulation software

With AutoMod simulation system it is possible to build models and to simulate detailed design, material handling and manufacturing processes. A model and simulation of the Knit on demand concept was developed in AutoMod™ Version 11.2.

5.3 In-data for the simulation

Production lead time data is based on information from machine equipment companies and own trials conducted at the School of Textiles in Borås. Customers shop entering data is based on an investigation at the fashion shop where the Knit on Demand shop will be situated. Each simulation is a period of time of 200 hours, where the opening hours of the shop represent 9 hours. These 200 hours represents approximately 1 month of shop opening hours.An exponential distribution is used to model random arrivals of customers into the shop with the expected value of 6 minutes. This means that a customer is believed to enter every sixth minute, but as the exponential distribution is memoryless the probability that a customer enters the shop within the next minute will not rise as times goes beyond the expected value.
Probability for the customer to start designing a self designed sweater is estimated to 10% and 50% of the customers who starts to work with the “Multiple choice design system” is estimated to buy a product. It is estimated that 50% of those customers will choose to add embroidery to the garment. Probability for the customer to buy a Designers Place sweater is estimated to 15%. After the production paying time is estimated to 90 seconds. In the model two persons are working in the Knit on Demand system. One person is working in the shop part of the system with guiding customers in the choice of product design, selling garments in Designers Place and manages the cash desk. The other person operates the Knit production section of the system with work concerning manufacturing of the garments. The simulation model is built with priority to the knitting machines as the knitting machines in the production

section are the most expensive investment of equipment in the concept and there by given the highest priority in the system. This means that if the operator works with another process he suspends this process and starts working with the knitting machine. The materials used for the products in the simulation are wool and cotton. The main difference between wool and cotton in the production is that time in the washing machine is longer for garments made of cotton as wool garments is much more sensitive for mechanical friction due to felting of the wool fiber. The probability for a buy of a wool- or cotton garment is set equal 50% for all products produced.

Table 1: Design in Shop, preparation and process lead times

Process	Knitting	Washing		Drying	Steaming	Sewing	Embroidery	Total process time	
Preparation	5	1		1	1	1	2,5	11,5	
Process time	55*	36	14	30	4	5	16	176	154
Total lead time	60	37	15	31	5	6	18,5	187,5	165,5

*The knitting time is triangular distributed between 35 and 70 minutes with a mode (most likely value) of 55 minutes. This because there are different knitting times for different models, thread breaks and that error also can occur.

6. SIMULATION RESULTS

To illustrate the results from the simulation, charts were made using the output data. The figures below show the summarized result of the simulation. As an example of one of the fifteen simulations shown in Figure 3, Demand fulfillment time for cotton and wool garments varies from 130 to near 300 minutes. Most garment samples are in the range of 160-220 minutes. The result shows that demand fulfillment time for the customer varies from 120 to 301 minutes. An average demand fulfillment time for cotton products is 206 minutes for cotton and 191 minutes for wool products (Figure 4). This means that from the point of sales to the final point where the garment is produced and the customer has paid for it takes in average 206- or 191 minutes depending if its cotton or a wool garment. At a minimum the customer could have (in one case) a wool garment in 120 minutes and a cotton garment in 137 minutes (Figure 4). The difference in time for wool and cotton garments is depending on the fact that there is a time difference in the washing process.

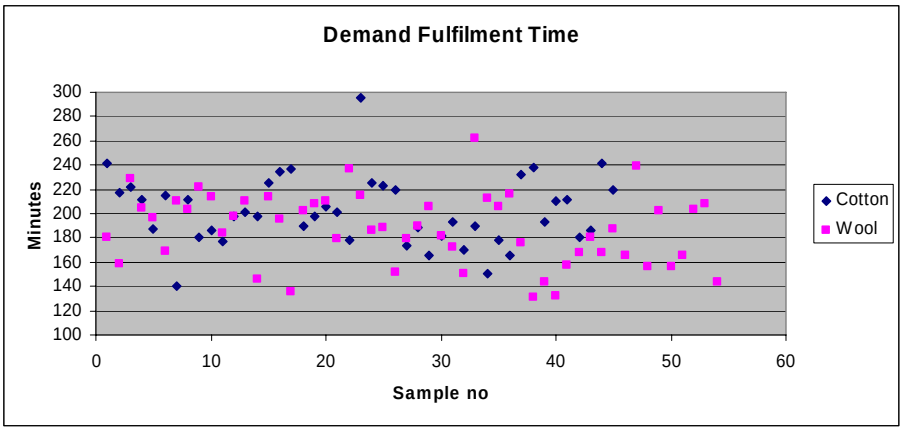


Figure 3: Demand fulfillment time for one 200 hour cycle simulation for own designed garments

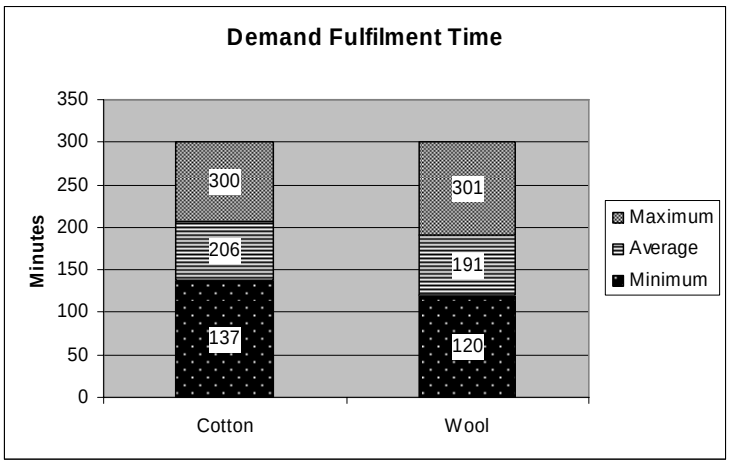


Figure 4: Demand fulfillment time for own designed garments produced during 15 simulations

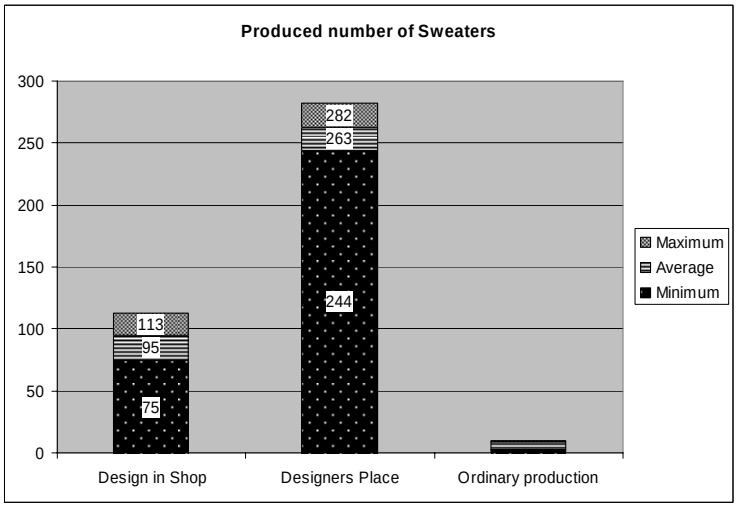


Figure 5: Number of product, produced and sold in Design in Shop in 15 simulations

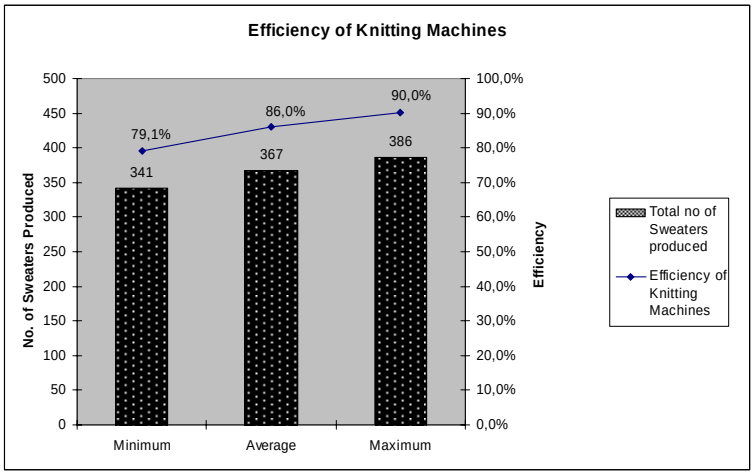


Figure 6: Knitting machines efficiency and total number of produced garments in 15 simulations

Figure 5 shows produced and sold number of garments in the different parts of the Knit on Demand system. In the Design in Shop part were customers choose options for an own designed garment there is a result of maximum 113 and minimum 75 garments with the average number of 95 garments. When it comes to Designers Place maximum amount is 282 and minimum is 244 with an average of 263 garments in the demand fulfillment process. The result of the simulations shows that the efficiency of the knitting machines is varying between

79.1 % as a minimum and 90.0% as a maximum value (Figure 6). The average efficiency of the utilization of the machines is 86.0%. Total number of garment produced on the knitting machines during the simulations varies from 341 to 386 with an average number of garment produced in all 15 simulations is 367.

7. CONCLUSIONS AND FUTURE WORK

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

Research question 1: What is customer demand fulfillment time for an own design product in the Knit on demand concept? The result of the simulation shows that the demand fulfillment time is between 120 and 301 minutes. The customer could have a garment in the range of 2 to 5 hours. A delivery of 2 hours requires a garment with a minimum knitting production time and without embroidery. This also means that there are no waiting times and no queues in the system. Research question 2: What is the efficiency of the knitting machines in the system? The result of the simulation shows that the efficiency of the knitting machines is 79.1% to 90.0% with an average of 86% which is a relative high grade of utilization. To improve the efficiency of the knitting machines the set-up times of the machines must be minimized. Research question 3: What is the performance in produced products for the different parts of the knit on demand concept? The performance in produced garments in the model and simulation set-up resulted in an average of 367 produced garments in the system. In average 95 garment was by customer own designed garments in the Design in Shop part of the system.

The aim of the research was to develop and describe the Knit on Demand concept and to develop a model for simulation. This has been done and in-data for the simulation and computer simulation in AutoMod has been performed. The simulations results can be further improved by shorten the process lead times even more. The pre-study of process data shows that the washing process is a bottle-neck in the production system. In the washing process the water must be heated in the washing machine before the actual washing starts, and this takes time. A solution would be to pre-heat the water so that the washing can start immediately when the garment is put into the machine. This could shorten time for washing considerably. This paper shows that an agile business and production system could cut lead time considerable from customer demand to customer demand fulfillment. In this paper is shown that a high fashion customized garment was designed, sold and produced in 2-5 hours. This work does not point out economical aspects such as price of the products or profitability of the concept in account; it just shows the design- and production process of the concept. It shows that there often are problems with demand fulfillment time in the fashion business and gives an example how this could be solved in the range of flat knitted fashion products.

Future work will be to study this business model further and to develop the different parts of the system. The multiple-choice design system must be developed and customized. Manufacturing processes has to be optimized. How to handle unsatisfied customers? Could the products be delivered to the customer directly? Or is it delivery by mail to the customers that is most suitable solution? Also the economical aspects of the concept have to be studied. This paper points out that the complete garment technology opens up new perspectives concerning customization in the fast fashion business of flat knitted products.

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