TOC and TQM Utilized in a Mass Customization Production Environment

– A Case Study at the Apparel Manufacturer Tailor Store International

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Abstract

Title: TOC and TQM Utilized in a Mass Customization Production Environment – A Case Study at the Apparel Manufacturer Tailor Store International

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Background: Mass customization has been identified as a competitive business strategy by both companies and academics because of its ability to incorporate the voice of the customer into companies' products and services. Although mass customization may sound appealing, the strategic concept is still developing and firms adopting this business strategy face several challenges. Production concerns are of high relevance since mass customization implies a high level of customer involvement in the product design. Since the areas are closely linked it is reasonable to ask how a mass customization strategy affects production concerns. Can companies relay on classic production strategy tools to make the most out of mass customization?

Purpose: The purpose of this thesis is to emphasize production management concerns derived from mass customization.

This is achieved by conducting a case study and cross breeding mass customization together with the management theories TOC and TQM.

Methodology: The methodology chosen in this thesis is a case study approach. This implies that both quantitative and qualitative methods have been used. The methodology contains a detailed review of the authors work process, including the methods used in the data collection process. To strengthen the analysis of the thesis, solutions inspired from the theoretical framework are implemented in the case study object's production.

Conclusions: The studied form of mass customization causes high production variances which increases the probability of creating production bottlenecks and thus enlarge the risk of limiting the production output. The main impacts of mass customization, affecting variance, are a high product variability derived from multiple product attribute choices. This thesis further concludes that mass customization implies a higher risk of product quality issues. TOC is considered a suitable management tool for mass customization manufacturers, since it highlights the concern of variance and bottlenecks. TQM is a suitable roadmap for mass customizing firms to achieve improvements of product quality.

Key words: Mass Customization, Total Quality Management, Theory of Constraints, Apparel Industry, Variance, Lead Time

Preface

A long time before this study was finalized the authors' established two overall goals concerning the execution of this master thesis. Firstly, the thesis should be conducted in a small or medium sized cooperation where we could make a significant contribution. Secondly, the company should operate abroad, preferably in a country with a culture diverging from the western culture.

With our minds set on these goals, Tailor Store served as an excellent case study company. We would like to thank Magnus Loodberg, Jan Höjman and Mats-Ola Ström from Tailor Store Sweden for their efforts making this thesis possible. We are highly grateful, and happy, that you believed in us and provided us with this excellent opportunity.

Further, we also would like to thank our tutors from Lund University, Carl-Henric Nilsson and Fredrik Nilsson. You gave us valuable support during the road to complete our work. Our communication went along smooth despite the large geographical distance between us. Gratitude is also forwarded to our reference group, Simon Engdahl and Petter Karle, who supplied us with relevant feedback and supported us with a language revision.

Last but not least, we would like to sincerely thank all the members of Tailor Store International. Nalin Pathirana, Shiroma Rathnayake, and Shyamalie Rathnayake, you took care of us during our three months in Sri Lanka and made us feel truly welcome and at home. We came as strangers, full of intentions, and left as good friends with a lot of great memories.

Lund, 2008-05-20

Daniel Estephan & Tobias Uppström

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1 Introduction

1.1 Background

Business is a constantly evolving process that is practiced by firms and studied by scholars and academics. New assumptions and theories emerge continuously, but only a fraction nurtures into new business concepts. From time to time, new radical business models are created. Through a wide adoption by practicing firms, these new concepts have the power to change the basis of how business is conducted. An example of such a fundamental change is the transition from small scaled craft production to low-cost mass production. This event took place during the early parts of the 20th century when mass production was popularized by Henry Ford (Womack & Jones, 1990). In 1970, a new frontier in business was anticipated by Alvin Toffler. Following an increased pace of technology development, Toffler proposed a business model that unifies custom made production and mass production. This seemingly contradictory blend is referred to as *mass customization* and the term was coined 1987 by Stanley Davis. Traditionally, firms tend to focus on applying either small scaled customized production or mass production, which utilizes economies of scale and cuts manufacturing cost (Pine & Davis, 1999, pp. 9-10). However, companies adopting mass customization strive to achieve both; customized products at a large scale, in a cost-efficient way.

Companies and academics have mutually identified mass customization as a competitive business strategy because of its ability to incorporate the voice of the customer into companies' products and services (Davis, 1987, Duray, 2000 & Pine, 1993). The growing customer demand of increased product variety, more features, and higher quality (Kotler, 1989) implies a promising prosperity of mass customization. The apparel industry is an example of a business field where this growing trend has been apparent. Firms contending in this environment seek alternative business models to stay ahead of competition. There are several examples of companies undertaking mass customization as a remedy for these changing conditions (Ulrish & Anderson-Connell, 2003). Clothes are a good example of a product where customization adds more value than adjustability and configurability. Consider a different example, customizing a car seat might not be desirable since it limits the seat to one driver – instead, an adjustable seat would be preferred in most cases. However, clothes normally do not have multiple users, and a product tailored for the individual customer is of high value.

Although mass customization may sound appealing, the strategic concept is still under development, and firms adopting this novel business paradigm face several challenges. A suitable question to ask is whether established strategic management tools apply to mass customization. Offering customers exactly what they want will place higher requirements on the production and is likely to be bound with special production concerns. For instance, quality assurance and quality control are likely to require increased attention. Assuring quality is usually accomplished by monitoring preferred quality characteristics. An increased number of customer options will likely generate new quality characteristics and hence complicate quality management (Silveira & Borenstein, 2000). This illustrates an actual production issue, with a direct link to mass customization. The example is far from solitary and according to Silveira & Borenstein, more specific and often practical questions raised by mass customization remain somewhat inconclusive.

1.2 Problem Discussion

A mass customization environment is likely to present new challenges to production and there are reasons for firms adopting mass customization to turn their attention to production matters. There are intuitively several fundamental differences between mass production and mass customization that raise different production concerns.

Initially, consider the variation of a mass customized product and how it may affect a production line. The potential variability concerns caused by mass customization is easiest illustrated by an example. A plain white shirt without any added customizable options will place less stress on the production line in comparison to a shirt that requires fabric matching (careful adjustment of fabric parts at assembly), and has special features, such as extra pocket or epaulets. Clearly, different levels of product customization could imply a higher variance regarding the time required to complete certain production operations. Also, customization will likely involve additional operations, such as adding pockets or epaulets, as the example above shows. Apparently, an increased level of customization could cause higher variance in the production. But to what extent does this affect the daily production output? Is it necessary for firms to consider these factors when managing a production line?

Another issue concerning mass customization and production is lead times. While mass production offers goods available "right now", mass customization requires the customer to design the product prior or during the assembly phase. Several studies conclude that a major factor increasing customer satisfaction is short lead times (Blocher & Chajed, 2007). A short lead time is vital to minimize the drawback of not having the option to immediately offer customers products when demand arises. Hence, designing a production that enables a rapid lead time is of large importance for companies undertaking a mass customization strategy.

Theory of constraints (TOC) is a well established management theory that encompasses the correlated areas; production, performance measurement, and problem solving tools. TOC techniques have been implemented and validated by several companies and systematically studied by multiple scholars. Examples from the industry and academic research mutually disclose an increased level of production output while reducing inventory, manufacturing lead time, and the standard deviation cycle times (Watson & Blackstone, 2007). As highlighted earlier in this chapter, these issues are of high concern for mass customization productions. Thus, TOC could stand as a suitable option when coping with production difficulties associated with mass customization.

The earlier remarks about quality assurance call for additional attention. Whenever a product is customized, a new set of quality characteristics will appear. To fully understand the meaning of this once more, consider the example of a shirt. A shirt with a pocket will introduce additional quality characteristics, just as a shirt that requires fabric matching will. An increased number of quality characteristics will raise the complexity in the production system. Another aspect to consider is the rate of products that must be verified by a quality control. To achieve a cost effective and rapid inspection, numerous firms choose to apply acceptance sampling. This implies that decisions about a batch are based on samples rather than 100% inspection (Fuchs & Kenett, 1998, p. 3). A high degree of mass customization employs a batch-size-of-one, that is; no product is equal to another (Anderson, 2004, p. 75). This would require every single product to be inspected if the previous inspection-based management style is employed. These conditions, caused by mass customization, are not trivial and should not be left unmanaged. The previous highlighted management strategy TOC addresses the larger systemic picture and avoids reducing the system to a set of processes (Dettmer W. , 1995). To be able to approach and administer the mentioned quality challenges and complement the systemic view provided by TOC, an additional management/production theory is preferred.

Total quality management (TQM) is an extensive management theory, which strives to achieve customer satisfaction through continuous improvement of product quality throughout the entire organization. TQM focuses on improving processes, but still includes hands-on improvement tools that enable implementation of quality improvements (Joel, 1999, pp. 1-23). For these reasons, TQM is considered a suitable complement to TOC regarding the quality issues that could be the effect of mass customization. The authors have not been able to locate any previous research combining the three subjects of mass customization, TOC and TQM. Based on the problem discussion the authors believe that there is a potential academic and practical value in merging these three theories.

To verify the highlighted challenges, and further explore them, this thesis is based on a detailed case study executed at a company adopting mass customization. *Tailor Store Sweden (TSS)* and *Tailor Store International (TSI)* are closely cooperating in the apparel industry and have chosen to incorporate a mass customization strategy together. TSS is a Swedish e-commerce apparel organization with the business concept of supplying custom made garments to a broad mass of private customers. TSS manages business strategy, marketing, product development, supply chain management and customer service. TSI produces custom made apparel garments, and is based in Sri Lanka. The sister companies are experiencing a rapid growth period and are challenged by production issues such as increased lead times and reoccurring quality issues, and thus constitutes as a relevant and interesting case study objects.

1.3 Purpose

The purpose of this thesis is to emphasize production management concerns derived from mass customization.

This is achieved by conducting a case study and cross breeding mass customization together with the management theories TOC and TQM.

1.4 Authors Proposition

Based on the argumentation in the problem discussion section and the given purpose, the authors are suggesting a theoretical proposition. This proposition will be studied, analyzed, and tested throughout this thesis.

> **Proposition:** Mass customization strategies results in increased production variance which raises the probability of reduced production output.

The authors suggest the reader to keep the stated proposition in mind when reading this thesis and critically reflect upon it throughout the thesis.

1.5 Thesis Outline

Chapter 1 – Introduction
The first chapter provides the reader with an introduction to the main subjects that will be examined in this thesis. A background discussion of mass customization, TOC and TQM is followed by a short presentation of the case study object. Finally, the purpose of the thesis is presented together with the authors' proposition.

Chapter 2 – Methodology
The second chapter introduces the reader to the used methodology. In this thesis, a case study approach has been chosen, implying that both quantitative and qualitative methods have been used. The work process is presented for the reader, including the data collection process, and a discussion about the verification of the thesis. Lastly, aiming to facilitate for the reader, a set of definitions is presented.

Chapter 3 – Theoretical Framework
The third chapter starts with a theoretical discussion. This discussion focuses on how the chosen theories are linked together and how they together form the developed theoretical framework of the thesis. The main theories used in the thesis are; mass Customization, theory of constraints and total quality management.

Chapter 4 – Tailor Store - The Case Study Company
The fourth chapter is a detailed presentation of the case study object Tailor Store, and continues to explain the link between TSS and TSI. The level of mass customization in TSI's production is determined, TSI's production setup is reviewed, and the impact of product quality is discussed. Finally, a problem discussion follows, concluding issues related to TSI and production.

Chapter 5 – The TOC Process at TSI
The fifth chapter reviles how the five step TOC process was realized at TSI. The first step is to identify production bottlenecks and the following steps contains solutions how to improve the previous identified constraints. The authors implement a product quality improvement system in TSI's production using TQM and provide TSI with a set of management tools. Thus, the chapter contains both practical implementations and theoretical recommendations, aiming to solve the stated production issues of TSI.

Chapter 6 – Mass Customization Production Concerns
The sixth chapter contains a theoretical analysis, focusing on the impact of production issues in a mass customization production. The theoretical framework and the conducted case study works as a foundation for this theoretical discussion. Further, the impact of mass customization in a production line is discussed, and the correlation between mass customization, TOC and TQM is debated.

Chapter 7 – Conclusions
The seventh chapter summarizes the findings and conclusions from the case study and the analysis. Finally, recommendations for future research are provided.

2 Methodology

2.1 Research Approach

"Case studies can be used to accomplish various aims: to provide description, test theory, or generate theory." (Eisenhart, 1989)

This thesis aspires to identify relevant production management concerns derived from mass customization. It is the authors' ambition to attain results solid enough to generate a foundation for a theoretical contribution. This contribution will be based on the linkage between empirical conclusions and the formed theoretical framework. By studying a case company, the authors are striving to develop and validate theory based on empirical reality, research literature, and common sense. The process of a case study approach most often begins with the collection of data, which is followed by an iterative process and the comparison of the gathered data and theory (Eisenhart, 1989). The authors argue that the case study approach is suitable in this thesis, since the approach typically combines different methods of gathering data, e.g. observations, archives, interviews and surveys. Consequently, the case study approach contains evidence that might be both qualitative and quantitative (Eisenhart, 1989). Further, a case study provides the researchers with a relevant research focus early in the research process, helping to narrow the extensive volume of available data. With a narrow focus, the researchers can use the various methods of data collection to triangulate, providing an extended substantiation and validation of possible hypotheses and findings (Eisenhart, 1989).

Another important fact to consider, when conducting a case study with the intention of generating new theory, is the formulation of the research problem. When initiating a case study approach, Eisenhart argues that investigators in some extent should avoid considering specific theories or hypotheses, and instead aim to begin the research with an open minded and clean theoretical slate. Eisenhart, however, admits that this is a hard thing to achieve practically, and the authors of this thesis did start the work by formulating a research problem and did have some references to relevant literature. However, by being aware of the facts discussed above, it is the authors' belief that the case study was approached with an open mind, maximizing the possibility to obtain an objective review of the case study and providing a good foundation for the upcoming theoretical framework.

2.2 Work Process

The overall work process for this master thesis was divided into five different phases, which can be seen in Figure 1. The purpose of the first phase, the *pre-study phase*, was to attain a wide-ranging knowledge of the apparel industry as a whole and the case study object Tailor Store. This phase implicated literature reviews and several personal interviews with the management of TSS. The pre-study phase also initiated the creation of a theoretical framework. This procedure however continued throughout the following phases. The creating of the theoretical framework contained a review of academic literature collected from several relevant databases. Performing a literature-study, the reliability is dependent on the personal ability to understand the text in a correct way, without omitting important information (Ekengren & Hinnfors, 2006). Considering the fact that two researchers conducted this thesis, this risk to neglect important information was minimized.

Further, Figure 1 itself is a result of the pre-study process and was utilized as a guideline for the subsequent work process. During the construction of the work process much thought was given to which research method to use. Due to the purpose of the thesis, a mix of different study methods was utilized, and it was therefore decided to use a case study approach. Furthermore, the pre-study elaborated a relevant scope for the thesis.

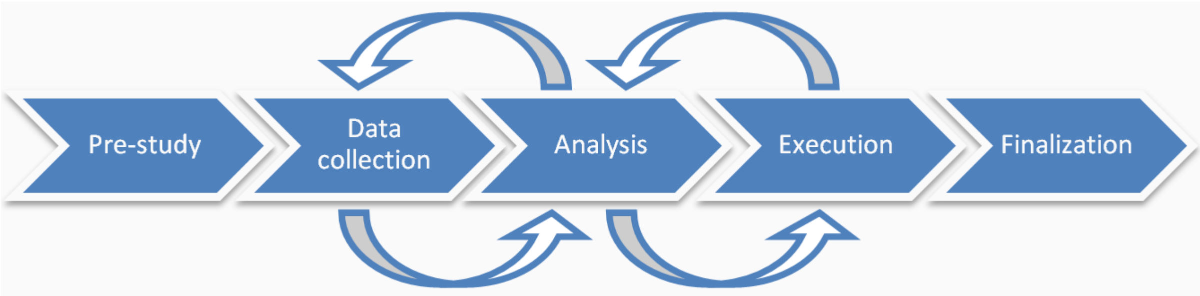

Figure 1: The work process.

The following phase is the *data collection phase*, which aimed at collecting relevant data from the case study object. The authors traveled to Sri Lanka, and spent approximately three months conducting observations and collecting data from the case study firm TSI. The gathering of empirical data was divided into a qualitative and a quantitative part. The qualitative data was collected mainly through interviews with staff from TSI's management and production employees. To manage collecting the quantitative data needed, a detailed production study of TSI was initiated. The data was focused on TSI's production line and the production process as a whole. The main goal was to collect data that support the process of identifying production bottlenecks. It should be emphasized that the phases following the pre-study were not completely isolated from each other. Hence, the iterative nature of the process implies that the phases occasionally merged together.

The next step in the work process was the *analysis phase*. During this phase the authors strived to solve the identified issues at TSI. Furthermore, the intention was to analyze the gathered data and use the developed theoretical framework to create analytical solutions. The analysis phase also aimed to create practical solutions to TSI and generate a foundation for theoretical contribution. While striving to create practical recommendations to TSI, the authors utilized a brainstorm process called *Creative Problem Solving* (Proctor, 1999).

During the execution phase, specific findings from the analysis phase were implemented into selected sections in TSI's production line. The objective was to further verify the findings by testing the solutions, measuring the results and generate additional material for the thesis's final analysis. This implied that new measurements were made and new data had to be collected and later analyzed. Thus, the execution phase and the analysis phase were in a large extent conducted simultaneously. The first part was an analysis of the gathered data compared with the theoretical framework, aiming to create practical solution to TSI. The second part was to implement the solutions, and thereafter collect new data, confirming the results of the conducted changes.

The finalization phase aimed to conclude the thesis and evaluate the completed work. The authors went back to Sweden and focused on answering the stated purpose and propositions of the thesis. Further, the objective was to critically evaluate the findings and conclusions.

2.3 Data Collection Phase

2.3.1 Qualitative Data

The qualitative data of this study were mainly collected through interviews. Collecting data through interviews makes it somewhat difficult to evaluate the reliability, considering that a respondent's opinion regarding a subject may vary from time to time. Factors affecting a respondent's opinion could for example be the way the interviewer is formulating the questions or the relation between the respondent and the interviewer. (Jacobsen, 2002)

The personal interviews were characterized by an open-minded climate, which created new findings and intriguing directions of the conversations. During the phases of data collection and analysis, semi-structured interviews were used. Due to cultural and language barriers it was important for the authors to proceed slowly during interviews to ensure that the questions and answers were interpreted correctly. Occasionally, an interpreter was used due to employees lacking knowledge of the English language. In these situations it was of importance to ensure that the answers were interpreted in a correct way. Therefore, the authors made it a habit to let the respondents read and confirm the written answers.

2.3.2 Quantitative Data

The largest amount of the quantitative data was collected during the phases of data collection and analysis. Three major studies were initiated in TSI's production facility during the observation phase. The studies were all used to gain a better understanding of the production of TSI, and further aimed to collect information used to identify potential production bottlenecks. The studies were divided into: (1) Production capacity, (2) Work in process and (3) Product quality.

2.3.2.1 Production Capacity

To calculate the manufacturing lead times in TSI's production, the production process was divided into 25 different production steps or sections. To obtain a process time for each section, the authors conducted fifteen time measurements from every production section to ensure that the data collected was reliable. Further, for each production section, fifteen measurement of the setup time were performed. The measurements were used to calculate an estimated standard deviation value for each production section. It is important to consider that when the authors were conducting the process time measurements, there are several factors that could have affected the results. The presence of the authors in TSI's production could affect the motivation of the workers. When observed, some workers might become motivated to work faster, while others might feel stressed and instead decrease their work rate. However, since several weeks were spent in the TSI production, it is the authors' belief that this impact could be partly diminished. Another relevant fact to consider is that TSI's production line is mainly manual, thus other factors could have affected the process times. Examples of factors affecting the workers are: individual employee characteristics like personal motivation, experience and knowledge, daily spirit, or tiredness. To increase the possibility of getting reliable results, the authors performed measurements at different times and also measured different employees. By being aware of these facts, the authors have been able manage the risks, aiming to maintain a high internal validity.

2.3.2.2 Work in Process

When studying the work in process (WIP) at TSI, it soon became obvious that there were a high amount of shirts in the production line. The queues of shirts were allocated in boxes belonging to the productions different sections. It was vital for the study to measure the quantity of shirts in the production line, to be able to identify the bottlenecks. Measuring the number of shirts in process turned out to be a task causing the authors some initial problems. Because of the large number of boxes holding inventory, substantial time was required to collect the different work in process levels. Further, to collect a satisfying amount of data this had to be performed at least two times a day during minimum seven days. The solution was to create an employee survey, and introduce this survey to the employees in TSI's factory. The authors dedicated time to ensure that every employee responsible for completing the survey fully understood how to fill in the survey correctly.

2.3.2.3 Product Quality

When conducting interviews with the TSI management, the subject of product quality was brought into attention. Several of managers and supervisors claimed that TSI had problems with product quality. In the case of TSI, if a shirt is rejected in the final quality control section, it is reversed in to the production line. The shirt is then immediately to be corrected by the responsible operator, who earlier caused the product damage. This is an obvious time waste which requires capacity in the production line. To map out the extent of the quality issues it was decided to measure the amount of rejected shirts in the final quality control section. Another survey was created by the authors and was provided to the employees working in the final quality control section. The same precautions used conducting the work in process survey was taken, to ensure that the concerned employees could complete the survey adequately. The quality control survey was used in the production line during nine working days, providing data the authors with necessary quality data.

2.4 Analysis Phase & Execution Phase

2.4.1 Management Workshops

During the analysis and execution phase, the authors were given the role as management consultants with the mission to support the management of TSI. To be able to perform changes in the production line, the authors aspired to reveal some concluded findings from the conducted theoretical analysis to the TSI management. Consequently, two management workshops were executed. The goal with the workshops was mainly to educate the TSI management in the basic concepts of TOC, striving to make them understand the main issues in the production.

During the management workshops the authors provided data to the management showing that some sections in the TSI production had a high variance. Further, by revealing the results from the product quality survey, the TSI management decided that a quality improvement program should be developed. The quality improvement program should aim to minimize the shirt damages, lower the rejection rate and consequently obtain an increased product quality. Further, when concluding that there was an existing high variance in TSI's production, it was mutually decided that TSI needed practical methods to deal with the negative impacts of the variance. The authors were given the task to develop these methods together with selected TSI supervisors.

2.4.2 Selection of a Test Team

The adequate approach was to apply the developed solutions to an isolated part of the production line. Since the time scope was limited and a narrow factor, the authors were provided with a stitching team in TSI's production line. This was considered a feasible solution and provided the possibility to perform changes within a specific team. The method of using a test team provided the opportunity to compare the results of the test team with the four remaining stitching teams. At the same time, the risk of negative disturbance in the entire production line was minimized. The chosen stitching team was considered an average stitching team at the time, based on the initial quality study and TSI management experience. The quality survey conducted during the data collection phase revealed that the test team was the third best team out of five during the observation period. Thus, the goal was to make this team the best team of TSI, regarding product quality.

2.4.3 Quality Improvement Program

With a test team provided, the authors spent a week analyzing the special team conditions in the production line. The goal was to lower the amount of the rejected shirts produced in the stitching team. The authors chose to utilize the framework total quality management. Before selecting TQM, several other quality improvement tools like lean and six sigma where discussed. However, after a thorough study of the most frequently used production quality tools, the authors decided that TQM was the most suitable for TSI. Hence, during one week, the authors performed several changes regarding quality (to read more about these changes see 5.3.2 Stitching Teams - Quality Improvement System, page 48). Thereafter, the authors measured the rejection rate of shirts during twelve working days. The measurements of the rejection rate were performed to cover all the teams, to be able to compare the results of the test team with the other stitching teams.

2.4.4 A New Box System

During the management workshops, the authors pointed out that the TSI production had a high production variance, which could cause bottlenecks in the production. Hence, it was concluded that a management tool was needed to deal with the process time variance. It was also decided that the test team was a good place to implement this tool. The solution, developed by the authors, was to create a new box system in the test team. It was decided that each station only was allowed to have a maximum of ten shirts waiting to be processed. Consequently, the stations were provided with new boxes and each box was designed to contain a maximum of ten shirts.

2.5 Internal Validity

The method used should in fact examine what is supposed to be examined, that is the internal validity (Bell, 2000). The authors have strived to keep an open research approach and to giving respondents with different references and backgrounds the opportunity to explain their version of the stated problems. By doing this, the authors believe that a higher overall validity is achieved. Further on, by comparing the gathered qualitative data with information retrieved from the quantitative data, the validity of the thesis was increased. When evaluating the validity of the quantitative data it was important to be aware of some risks. Since TSI is using the production strategy mass customization, not every working operation is homogenous. This means that time measurements of a single operation performed by the same employee might fluctuate more than within a classic mass production strategy. Because of this fact, the authors discovered large variations considering the time measurements conducted during the capacity study. Another explanation to the variation was different skills and experience between employees.

2.6 External Validity & Generalization of the Theoretical Findings

External validity examines to what degree it is possible to generalize the conclusions from the thesis. Further on, it explains in what extent the findings are valid for other organizations, in e.g. an industry context or within an extended timeframe. Considering the fact that the methodology approach is a case study, containing both quantitative and qualitative data, it is difficult to evaluate the external validity to a certain degree. However, the authors argue that the propositions and the conclusions in this thesis could be valid for other firms in the garment industry, using a similar production strategy and a similar level of mass customization as TSI. The authors leave it to the reader to decide if the results in this thesis can be further generalized. However, since this thesis concerns only one case study, the authors recommend other academic scholars to test the authors' results and findings through further research.

2.7 Definitions

To facilitate the understanding of this thesis a set of definitions were established during the work process. These definitions derive from academic definitions and have been adjusted and developed to fit the studied case company TSI and the apparel industry. The reader is recommended to briefly study the definitions at first and when reading chapter 5 The TOC process at TSI, return to this section and study the definitions more thoroughly.

Throughput – the rate at which a company generates money through sales. When utilizing mass customization sales normally occur prior to production. This implies that throughput equals the rate of which products is manufactured (products manufactured/unit time). In the case of TSI, throughput is equal to produced shirts during a certain time period, e.g. produced shirts/day.

Work in process (WIP) – orders that have entered the production line and have not yet been packed. In the case of TSI, WIP is equal to the amount of shirts that are located in the production line and not yet delivered.

Lead time – the total order-to-delivery time of a product. In the case of TSI the lead time is the time from a single customer order on the TSS website to the final delivery of the customized shirt to the end customer.

Manufacturing lead time – the elapsed time from when a customer order enters the production line until it is packed and ready for transportation. In the case of TSI this is equal to the time a shirt is physically located in the production line. With aid of queuing theory the manufacturing lead time can be derived based on the two previous definitions WIP and throughput.

$$Manufacturing\ lead\ time = \frac{Work\ in\ process}{Throughput} \quad (^1)$$

Process time – the time required to for a station to process a product, bringing it closer to become output. An example of process time is the time it takes to process a shirt at a specific section. For example, at the cutting section of TSI the average process time to cut a shirt is approximately 26 minutes.

Setup time – the time required by a working unit to prepare to process a new product. In the case of TSI this equals to the setup of processing a new shirt. For example, the setup time for a TSI stitching operator to prepare for a new shirt is 1.5 minutes, which includes switching thread in the sewing machine.

Standard Deviation –The standard deviation reveals on an average how far the process time varies from the mean process time. See formula below.

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\mathrm{x_i} - \bar{\mathrm{x}})^2}$$

σ = standard deviation, n = number of measurements, x_i = current measurement,

$\bar{x}$ = average measurement

Variance – Is the standard deviation squared and thus variance also measure divergence. The term variance is frequently used throughout this thesis and refers to production divergence. When referring to measuring variance the standard deviation is considered.

[1] This is a variant of Little's law (Körner, 2003)

3 Theoretical Framework

3.1 The Forming of the Theoretical Framework

This thesis takes foothold in three major strategic management theories. As outlined by the introduction chapters these are; mass customization, theory of constraints (TOC) and total quality management (TQM). A brief description of the linkage among these theories will now be given.

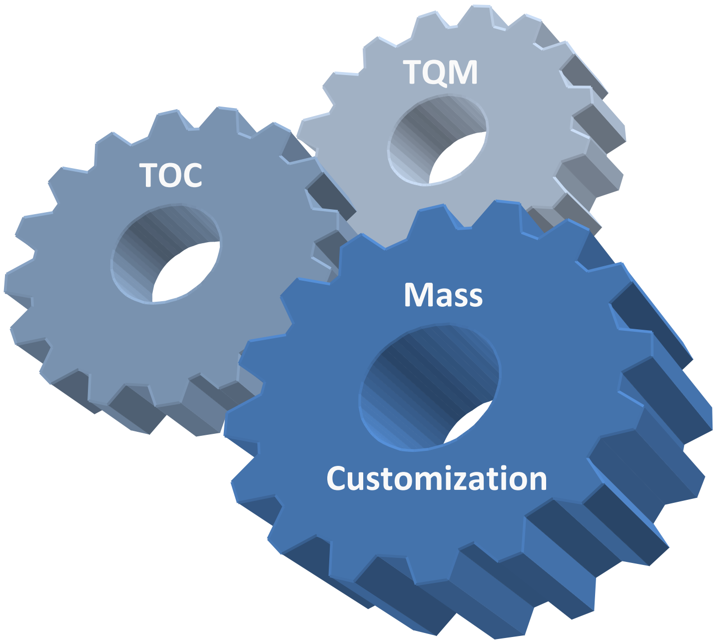

Figure 2: An illustration of the theoretical framework with the three combined theories Mass Customization, TOC and TQM.

Mass customization is suitably viewed as a management philosophy which defines the basis of how a company conducts business. It is not simply a tool that can be adapted by a firm without major reconstruction of the organization and the production. Because of this fact, mass customization is chosen to be viewed as an environment where business is conducted. This places mass customization in a central role among the selected theories which is symbolized by the larger cog in Figure 2.

The two remaining theories, TOC and TQM, are considered as supporting management tools. These tools have several comparable characteristics. They are both comprehensive theories with a high level of usability in production environments. The theories are also perceptive, which means they will not only identify and describe problems but also offer a roadmap to finding solutions to the recognized issues. TOC and TQM are singlehandedly applicable, but combining them could provide additional value. For instance, TQM urges extensive improvements and stresses managers to get every employee involved (Deming, 1988). With improvement measures spread out over the complete organization, extensive improvements can be hard to identify. Crossbreeding TOC and TQM could help companies to focus TQM efforts where they are needed the most, instead of distributing improvements across the complete production chain. This way, a result with higher impact can be achieved.

Consequently, combining the two theories TOC and TQM together with mass customization provides a solid foundation which facilitates coping with issues related to a mass customization strategy.

3.2 Mass Customization

3.2.1 Introduction

Alvin Toffler anticipated the first notion of the term mass customization, in the year of 1970, and Stan Davies coined the term 1987 in the book *Future Perfect* (Radder & Louw, 1999). Duray (2002) argues that mass customization is; *"a paradox-breaking manufacturing reality that combines the unique products of craft manufacturing with the cost-efficient manufacturing methods of mass production."* Consequently, most experts on the subject acknowledges mass customization as some sort of oxymoron, linking two apparently contradictorily notions together, providing the customers with individually designed products and services on a mass basis (Duray R. , 2002). Below is an illustration showing the emerging market of mass customization (Svensson & Barfod, 2002).

Figure 3: The emerging market of mass customization (Svensson & Barfod, 2002).

Historically, firms used production strategies that either supported customized crafted products or standardized mass-scale products. Typically crafted products intend a process where the customer to a large extent designs and specifies the product. On the other hand there is mass production, a product process for making highly standardized products in large scale, especially taking into consideration factors such as efficiency and low production costs. In contrast to crafted products, the customer has lower involvement in the production process within mass production, making the products characteristically standardized. (Duray R. , 2002) There is a value in acknowledging the distinction between product variety and mass customization. Product variety means that one can satisfy a larger amount of customers, while mass customization gives the customers the possibility to directly influence the product design and product specifications (Duray & Ward, 2000).

Today's fierce business environment is forcing most organizations to change more rapidly than ever, making flexibility a desired and obligatory ability. Given the facts of globalization, fast technological progress, and severe competition, the mass production strategy is increasingly being replaced by other more flexible production strategies (Hart, 1994). As a direct response to these factors, mass customization has become a manufacturing strategy of growing importance in several industries. A fact is that organizations who continue processing mass production will struggle to properly respond to changing customer demands making the unpredictable nature of the marketplace an inconvenient place. On the other side, organizations using flexible strategies, such as mass customization, have a larger possibility to adapt to the modern flexible business environment. Thus, mass customization is making it possible for firms to turn those challenges to opportunities, armed with agility and rapid responsiveness as main arsenal. (Silveira & Borenstein, 2000)

3.2.2 Definition of Mass Customization

The meaning of the term mass customization has been developed and altered during the last three decades. Davies originally defined that under conditions of mass customization; *"the same large number of customers can be reached as in mass markets of the industrial economy, and simultaneously they can be treated individually as in the customized markets of pre-industrial economies"* (Davis, 1987, p. 169).

A couple of years later, Pine defined mass customization as an organization process existing in different industries, supplying management tools and technology to provide a variety of products and customization through quick responsiveness and flexibility (Pine & Davis, 1999). Hart continued with a two-folded definition, the first being on a visionary and platonic level, namely to provide the customer with anything they want profitably, any time they want it, anywhere they want it, any way they want it. Obviously this is only an utopia, and Hart narrowed the definition to be of more practical nature, defining mass customization as *"the use of flexible processes and organizational structures to produce varied and often individually customized products and services at the low cost of a standardized, mass production system"* (Hart, 1994).

The upcoming buzzword modularity was included in the definition by Silveira & Borenstein, who were labeling mass customization as; *"Building products to customer specifications using modular components to achieve economies of scale."* (Silveira & Borenstein, 2000). Other scholars later on defined mass customization as an organization capability to offer individually tailored products in large scale that meets the customers' needs, maintaining the efficiency of mass production (Zipkin, 2001), (Tseng & Jiao, 2001).

To shed light on the subject of defining mass customization, Kumar identified two reappearing factors. (1) The product delivered to the customer should be close to the desired; that is, the product should have a high level of customization. (2) The price of the product should correspond to the price that the product would command if it was produced using mass production. (Kumar A. , 2004)

In this thesis the authors have chosen to define mass customization as a flexible strategic process based on two main parameters; (1) the production should be able to provide products of a significant level of customization to a large number of customers, (2) The efficiency of mass production should be maintained and simultaneously the product should fulfill customer needs.

3.2.3 Levels of Mass Customization

Several scholars have made attempts to classify different levels of mass customization. Determining different levels of individualization is considered a relevant topic in the mass customization debate. The mass customization frameworks have a wide ranging, from smaller adjustments and adaption of products up to pure customization, including design, production, assembly, and delivery. (Silveira & Borenstein, 2000).

3.2.3.1 The Four Faces of Mass Customization

In the article "The four faces of mass customization", Gilmore & Pine (1997) define four different levels of mass customization:

1. Collaborative
2. Adaptive
3. Cosmetic
4. Transparent

1. Collaborative Customization
In this level, the firm is striving to create an ongoing dialogue with the customers. This intends to help the customers express their explicit needs, while the customizer must do everything in its power to create a specific product or service that fulfill the articulated customer needs. Collaborative customization is suitable for business when the customers have difficulties to clearly articulate their needs, for example in some design businesses. In the designer example, the customer will most often be frustrated if the firm would offer various product options instead of offering a dialogue, making the customer pat of the design process (Gilmore & Pine, 1997).

2. Adaptive Customization
The adaptive customizer offers a standard product which later can be altered by the customers to suit the specific customer needs and wishes. This is particularly useful for customers who want the product to perform differently on different occasions. With some minor changes from the customer the product can be used under a variety of circumstances.

3. Cosmetics Customization
The cosmetic customizer is presenting a standard product that differs to different customer segments. The core product in itself is not altered or customized, but the product is displayed or packaged individually for each customer. This is a fitting concept when customers use a product in the same way, but want it presented in different ways. Even if the product itself is not customized the value of specific packaging is real for the customer, making the whole offer customized. An example of cosmetic customizers is garment producers offering the consumers to embroider their names or initials on shirts or cell phone manufacturers offering the customers the possibility to choose the color of the cell phone cover.

4. Transparent Customization
The transparent customizer gives the specific customer a unique product or service without the customers' explicit knowledge of the customization. The firm needs to monitor the specific customer needs without an immediate interaction and make a customized offering within a package that is standardized. This is often used when the customers want to avoid to continuously expressing their needs. An example could be a firm that delivers stock material to a customer. The customer wishes to have a balance between a small stock and no shortage of needed products. The transparent customizer fulfills this customer need by using a just in time system customized to the customer without continuous interaction.

3.2.3.2 Classification Matrix
Duray et al (2000) made a different classification of mass customization, arguing that distinctions among mass customizers can be made on the level of customer involvement and the type of modularity employed by the firm. Combining the two interrelated dimensions of customer involvement and modularity type generate four archetypes of mass customizers which can be observed in the classification matrix in Figure 4.

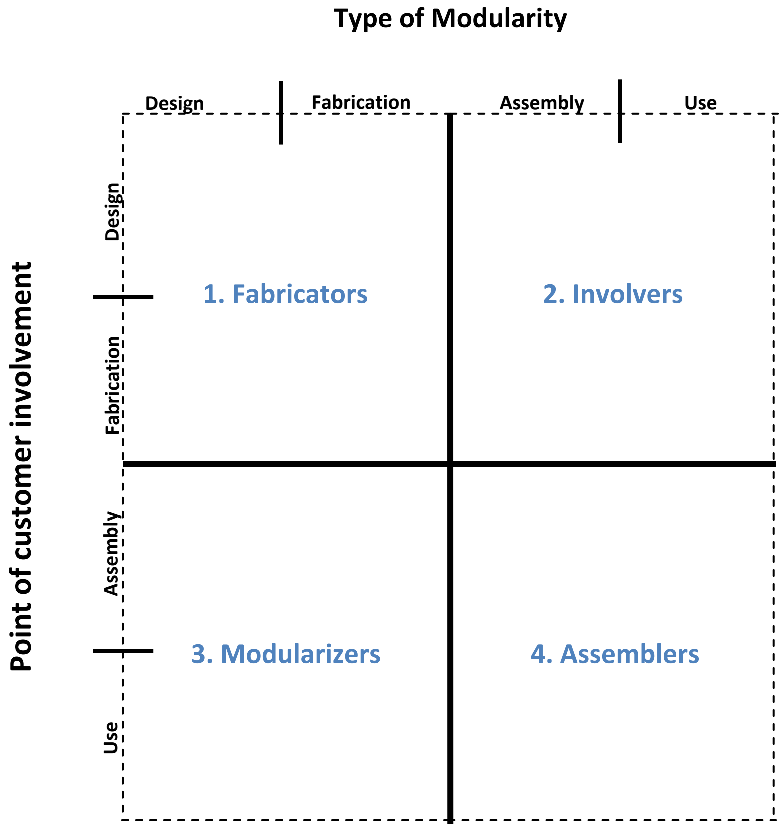

Figure 4: Classification matrix (Duray et al 2000).

1. Fabricators

The fabricators are including customer involvement and modularity during the design and fabrication phases, when major changes of design and functionality can be made. The customers need to be involved early on in the development process which gives the firm the possibility to fabricate a highly customized product. This means that fabricators almost utilize a pure customization strategy. However, the existing component modularity is providing the firm with an edge compared to customization through traditional craftsmanship.

2. Involvers

The involvers integrate the customer involvement in the product design during the design and fabrication phase, but the modularity is only used during the assembly and delivery phases. Thus the customer involvement comes early in the process but the firm does not manufacture any new specific customer modules. The customer needs and individual specifications are fulfilled combining standard modules, which imply that no new modules are created for the customer. Therefore, involvers capture a larger benefit of economies of scale compared to fabricators, and at the same time maintain a high level of customer involvement.

3. Modularizers

The modularizers are involving the customers during the assembly and delivery phase while the modularity is approached during the design and fabrication phase. This means that the customers do not express their unique needs until the phases of assembly and use. In other words, customizers called modularizers use modularity early in the production process, although the customization has not yet occurred.

For example a furniture mass manufacturer making sofas could use modularity in the design phase, which later gives the customer the opportunity to choose a specific frame among other choices. Later in the assembly phase the customer can also choose from a certain amount of fabrics, giving the product some degree of customization. Hence, modularizers combine the non-customizable modularity in the design and the fabrication phases with customizable modularity in the later phases of assembly and use.

4. Assemblers
The assemblers use an assemble-to-order type of customization which is the lowest degree of mass customization compared to the three above. The customer involvement and the modularity occur in the assembly and use phases. The major difference between an assembler and a mass producer is that the products provided by an assembler have been utilized in a way so the customer is involved in the product specifications, which gives the customer various alternative choices. This means that the customer will feel that the product is customized. For example, Dell is an example of a famous assembler, providing the customer with various options to personal computers, allowing the customers to specify which component to include in the final product.

3.2.4 Criticism of Mass Customization

There are several examples of success stories involving implementation of a mass customization strategy which has improved firms' strategic and financial performance (Duray 2002; Pine 1993). However, the authors would like to emphasize some words of caution in believing that mass customization is a miracle cure to all possible problems a firm may face. Naturally, an appropriate financial and strategic analysis must be reviewed before the application of a mass customization strategy. Furthermore, the upcoming of mass customization does not categorically imply the end of mass production, since the two different strategies could work side by side. There are examples when an optimal combination of mass customization and mass production has proved to outperform any one of them individually in a dynamic market environment (Kotha, 1996).

One must also be aware of that adopting mass customization requires the company obtaining certain abilities. The firm needs an elaborate system to thoroughly elicit specific customer needs. If the firm fails to properly gather this crucial customer information, it will most likely have extensive problems manufacturing unique customized products. A successful mass customization strategy also, in most cases, implies the need of a successful direct-to-customer logistics system. If the firm should fail to deliver the customized products to the customers within an acceptable timeframe, the customer will be highly dissatisfied. (Zipkin, 2001) Finally, it is important to highlight that a higher degree of customization or a larger variety of product choice not necessarily means that customers will be equally more satisfied or will be willing to pay a higher premium price. It is vital to understand that there is an existing optimum point where the value of a certain level of customization is maximized. (Kumar A. , 2004) To summarize, mass customization is naturally far from the only viable approach to a competitive business strategy, but under the right circumstances it has doubtless the potential to be highly successful, considering both strategic and financial values.

3.3 Theory of Constraints (TOC)

Theory of constraints is a management theory that addresses the larger systemic picture. TOC was introduced 1984 via the bestselling book *"The Goal"*, which is written in the form of a novel by Eli Goldratt, a physicist from Israel. TOC adapts a holistic approach and views a business as a system with resources linked together to reach established goals (Husby, 2007). The theory is generally applicable and the methods have been utilized by a large quantity of companies, in a large number of industries. The theory is still undergoing evolution and has moved from being interpreted as a production scheduling and controlling tool to an extensive management philosophy, spanning numerous operations management sub-disciplines (Watson & Blackstone, 2007).

3.3.1 What is a Constraint?

According to Goldratt, chains are a suitable analogy to business systems. What determines the strength of a chain? Applying a burdening force to the chain will eventually cause the chain to break. It will fail at only one point, and this point marks the chains weakest link. Consequently, the strength of a chain is determined by its weakest link. The weakest link limits the chain from not breaking and there is only one weakest link, since the chain will not break at several places at once. Similar to the narrow neck of an hourglass, that single constraint limits the output of the entire system. Goldratt concludes that there is only one constraint in a system at any given time, and this constraint will, if allowed to prolong, limit the output of the entire system (Dettmer W. , 1997, pp. 7-8).

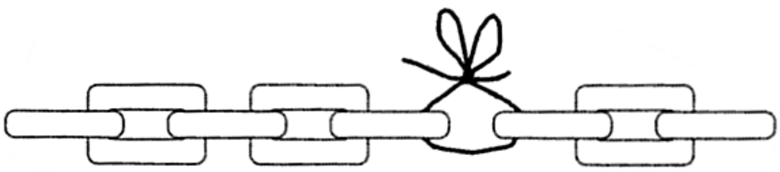

Figure 5: TOC identifies the weakest link of a chain (Watson & Blackstone, 2007).

In the Goal, Goldratt defines a constraint/bottleneck in the following way:

> *"A bottleneck is any resource whose capacity is equal to or less than the demand placed upon it."*

To fully understand this statement an explaining example will be given. Picture a basic production system that inputs raw materials, process the materials through a given number of steps and turns them into finished products. Each of the production steps has an individual daily capacity, indicated in Figure 6. The average market demand is concluded to be 50 units per day. Will the production meet the market demand?

Production step 3 will limit the output of the complete production because it cannot produce more than 45 units per day. The output from step 3 will also apply to the subsequent steps since the steps are dependent of each other. Regardless of how many units the following steps are capable of producing, they will not be able to produce more than what step 3 provides them with.

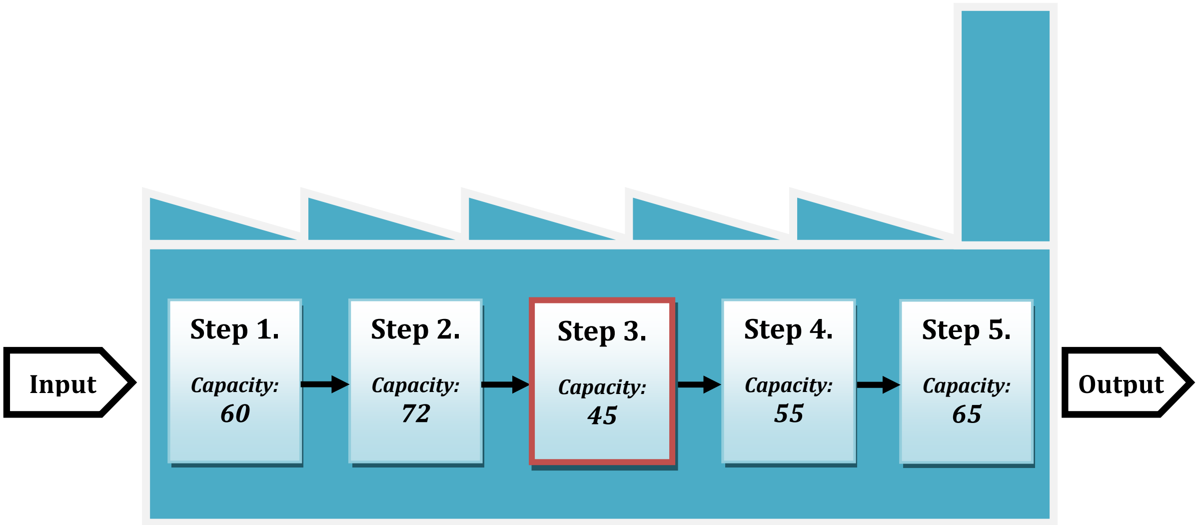

Figure 6: Production example with a constraint (Watson & Blackstone, 2007).

Since step 3 produces less than the demand placed upon it, it fulfills the criteria of the definition and is declared as a constraining resource or simply a bottleneck. Consequently, the correct answer to the given question is that the production will not meet the market requirements; it will only deliver what the bottleneck is capable of, 45 units per day. Improving the ability of the constraint to 55 units per day will remove the constraint and the market demand will be reached. The extent of TOC is not simply limited to production. If the market is included in to the problem scope the market/sales organization suddenly becomes the constraint. The factory is able to provide 55 units but the market can only accept 50, in other words the production will have excess capacity.

TOC seek to channel improvement efforts, for maximum immediate effect, by strengthening the systems constraints. Explicitly this means that TOC emphasize addressing the weakest link and ignoring, at least temporary, the non-constraints (Dettmer W. , 1997, pp. 9-10). Further, the production example also clearly shows that the optimum performance of a system as a whole is not equal to the sum of all the local optimum systems. For instance, it would not be necessary for step 2 in the example above to constantly produce at its local optima, 72 units?

3.3.2 What is the Goal?

In *The Goal*, Goldratt raises the fundamental but still very important question; what is the ultimate goal of a commercial organization? Diverse answers will most likely be obtained, subjected to whom the question is given to, but in Goldratt's book the answer is obvious. The overall goal of a company is simply to achieve long term profit, without it the organization will cease to exist. Managers stuck in day-to-day operation, surrounded by a large variation of challenges and performance indicators, faces the possibility of losing focus on this fundamental goal. Goldratt criticizes and challenges traditional financial accounting methods and claims that in some cases these indicators move the attention away from the overall goal and in contrast tend to cause suboptimization (Goldratt & Cox, 1984).

Three global performance measurements are traditionally used to supervise a company's ability of making money. These are; net profit (NP), return on investment (ROI), and cash flow (CF). TOC makes use of these traditional measures for global performance but states that they are not applicable at the subsystem level. To seal this breach and to highlight the business ability of generating profit three business unit/plant level measurements are used. These measurements provide a straightforward method of observing the effects of local changes and decisions on the entire systems performance (Watson & Blackstone, 2007).

- *Throughput* – The rate at which the entire system generates money through sales.
- *Inventory* – Includes the money the system invests in items it intends to sell.
- *Operating Expense* – The money the system spends to turn inventory in to throughput.

For a manufacturing company, throughput is the manufactured products which generate sales. Finished products that have not yet generated money do not account as throughput. Inventory includes raw materials, unfinished goods, purchased parts and other items intended for sale. Additionally, inventory consists of investments made by the organization in equipment and facilities. This is contrary to the traditional definition of inventory but since equipment investments ties up money and eventually, when obsolete will be sold, they can be considered as inventory. Operating expenses consist of consumable supplies, direct labor and similar expenses which are required to turn the inventory into throughput. Depreciation of assets is also considered an operating expense, since it represents the value of the "consumption" of a fixed asset (Dettmer W. , 1997, pp. 15-18).

If organizations' goal is to make money the correct combination of these measurements will ensure progress toward this goal. Goldratt argues that these three dimensions are interdependent. That is, a change in one will automatically result in change in at least one of the other two. For instance, increased throughput will likely require more inventories. Basically, the overall goal of achieving long

Figure 7: Definition of throughput, inventory and operating expense (Watson & Blackstone, 2007).

term profit can be realized by continuously working in the direction of increasing throughput, while decreasing inventory and operating expenses. Where should a firm focus its efforts? Theoretically there is no upper limit to incensement of throughput but in reality most often the market will set the limit. Inventory and operating expenses are necessary to create throughput and have a limited effect on how much money the organization can save. Primary attention should thus be given to increased throughput, not to cost savings, which companies normally priorities when exposed to escalating competition (Dettmer W. , 1997, pp. 17-19).

3.3.3 Five-step Improvement Process

To facilitate the organizational goal of maintaining long term profit, TOC provides a cyclic tool compiled by five sequential steps (Goldratt & Cox, 1984).

1. Identify the constraint(s)
2. Decide how to exploit the constraint(s)
3. Subordinate everything else to the above decision
4. Elevate the constraint(s)
5. Repeat the cycle and avoid inertia

(1) The first step of the process is to locate what part of the system represents the constraint. The constraint could be a physical bottleneck or it might even be an organizational policy. (2) When the constraint is located it should be exploited. In the context of TOC this simply means to squeeze maximum efficiency from the constraint in its existing configuration. In a production environment an obvious action would be to avoid all breaks and interruptions. (3) Once the constraint has been identified and maximized, the remaining parts of the system should be synchronized to the constraint. The constraint could be considered as a drum, which sets the pace of all other operations. Certain non-constraints should be planned to run with extra capacity to guarantee input to the constraint, which avoids starvation and loss of potential throughput. This will also most likely cause some parts of the system to idle from point to point, which is contradictory to local process efficiency. (4) If the two previous steps did not eliminate the constraint, next step is to elevate the constraint. Since the constraint is still limiting the performance of the system, despite making it as efficient as possible, the next step is to increase its capacity. This should be carried on until the constraint is removed. To distinguish between exploiting and elevating simply consider exploiting as changing the way a constraint is utilized without spending money, while elevating requires money investments to increase the capacity. (5) Finally the process should be repeated. Find the next constraint that limits the system's performance and strengthen this also. It is advised to not let inertia prevent the process from proceeding, since behind the current constraint a new one hides.

These five steps provide a reliable tool for organizations to consistently focus on what is really important, that is the organization's constraints (Dettmer W. , 1998, pp. 14-16).

3.3.4 Variation & Dependency – The Source of Production Constraints

All production bottlenecks have two underlying fundamental causes in common which contributes to their existence. These phenomenons are *variation* and *dependency*. Every system, including its subunits, will be exposed to variation over time. Variation is simply described as inconsistency and implies that a system will not consistently perform as expected. Each cycle of a single system component will fix around a desired value. Depending on the characteristic of this component some values will be close to the desired value and some will in a larger extent diverse from it (Dettmer W. , 1998).

Dependency is equivalent to the existence of a relationship with one or more components in the system. Dependency is inherent in almost every production system and can span from simple sequential relationships to complex dependency systems with one part of the system possible affected by several others. Because of dependency, a production unit cannot be optimized isolated, since prior components will deteriorate the maximum capacity of the subsequent system units. This relation is valid for the complete system and thus requires a holistic approach to avoid sub optimization.

A simple, yet illustrating example of the two concepts is given by Goldratt in The Goal. A production system is simulated with the help of a dice, a set of matches and a couple of bowls. The bowls represents components in a production system and holds the current unfinished products waiting to be processed, in other words, a stock. The unfinished products are represented by the matches and finally the dice defines a certain components capacity for a given iteration. When the dice is hit, the number of eyes decides the current station capacity.

A system component cannot process material which has yet not been released by the previous component. Hence, a system component's production will not exceed the current stock of unfinished products. This criterion spawns a sequential dependency. The average capacity of the system is 3.5 because the sum of the dice's number is:

$$1 + 2 + 3 + 4 + 5 + 6 = 21$$

When divided by the number of faces of the dice the average is obtained:

$$^{21}/_{6} = 3.5$$

The capacity will differ during each cycle and a value between 1 and 6 is expected. This resembles the inherent variation in a production system. Even though each system component isolated has an expected output of 3.5 the system as a whole will not output 3.5 units per cycle. A simple simulation with 5 bowls, cycled 10 times will basically always render a lower output then the expected 35 (3.5 x 10 = 35). The explanation is simply that variance will give lower average production at single units periodically. The temporary lower production will propagate to the following parts of the system, because of dependency, and will also lower these units production unless the components have a stock of unfinished material.

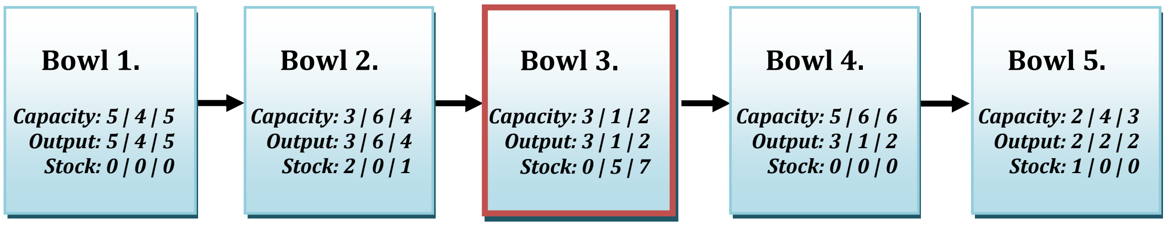

Figure 8: Part of a simulation which illustrates the effect of variation and dependency.

Figure 8 illustrates a part of the simulation and clearly shows that the output from the system, which equals the output from the last bowl, is lower than expected. During three iterations the system outputs the value of 6 (2 + 2+ 2) which averages an output of 2 units per cycle. This occurs even though the total average system capacity of 3.9 is sufficient.

$$Total\ average\ capacity = \frac{Total\ capacity}{\#\ of\ iterations * \#\ of\ bowls} = \frac{59}{3 * 5} \approx 3.9$$

The explanation to the low output is found earlier in the chain. Notice that bowl 3 has lower output than expected, caused by variance. The two remaining resources are affected, because dependency exists, and cannot produce at their own potential capacity. Therefore bowl 3 temporary becomes a bottleneck and thus limits the output of the complete system.

3.3.5 Criticism of TOC

Although TOC is a widely accepted theory it is also subjected to criticism. A major concern and criticism turned against TOC is the opinion that the theory only provides a short term scope with relation to product costing, capital investment decision and strategic planning (Watson & Blackstone, 2007). TOC have been criticized for trying to compensate traditional performance indicators, such as cash flow, without considering the need for long term vision in executive decision making. This leads to confusion regarding how to forge a link between the TOC performance measurement system and long-term planning (Dettmer W. , 1995).

Another frequent occurring voice of negativism aimed against TOC is the one categorizing the theory as a strict managerial tool. Critics claim that TOC leaves little involvement of workers; which might imply difficulties in creating acceptance for the organizational changes a TOC application might entail. It is thus important that the management actively strives to involve concerned parts of the organization in the TOC development process (Nave, 2002).

3.4 Total Quality Management (TQM)

"…quality alone is no longer a competitive weapon. It is the price of admission just to play the game." (Dettmer W. , 1995)

3.4.1 What is Quality?

The first striking thought concerning quality is the most obvious: What is quality? This is a recurrent question in the academic debate, and has been so since quality became a buzzword in management and business in the middle of the twentieth century. Even though the tools and strategies used studying quality has changed during the years, the fundamental customer requirements seem to be basically the same. However, the trend in most industries is that the customer no longer desires high product quality, nowadays the customer demands high quality. For a long time, the expert academics on the subject have been debating how to define quality, and this question has yet to be fully answered more than fifty years later. (Hoyer & Hoyer, 2001)

Investigating the topic further provides as many definitions as number of scholars studying the subject. One can establish that there exists no general agreement on defining quality. However, in the article "*What is quality?",* Hoyer & Hoyer conclude that generally there seems to be two main categories that defines quality; (1) The first one is delivering products or services whose characteristics fully satisfy a fixed set of specifications, which often are set by a numerical analysis. (2)The second is simply those products or services with characteristics which fully satisfy customers' expectations. When mentioning quality further on in this thesis, the authors' has the intention of defining quality due to the second category. Consequently quality is broadly defined as characteristics of a product or service satisfying customer expectations.

3.4.2 What is Total Quality Management?

Total quality management (TQM) covers an immense spectrum of methods and approaches. Like most theories concerning quality, TQM has its origin in the Japanese manufacturing industry. (Waldman, 1995) Dettmer (1995) argues that TQM focus on continuous process improvement, while Sashkin & Kiser (1993) views TQM as a part of a reigning corporate culture. Not surprisingly, there are various definitions of TQM. Dahlgaard define TQM as;

> *"...a corporate culture characterized by increased customer satisfaction through continuous improvement, in which all employees in the firm actively participate." (Dahlgaard & Dahlgaard-Park, 2006)*

While Hellsten and Klefsjö view TQM as:

> *". . . a continuously evolving management system consisting of values, methodologies, and tools, the aim of which is to increase external and internal customer satisfaction with a reduced amount of resources." (Hellsten & Klefsjö, 2000)*

Taking the above into consideration one can settle that TQM somehow should be related to increased customer satisfaction. Dettmer (1995) argues that TQM is focusing on process control and process improvement, emphasizing on improving individual processes, and then forging the results together. The authors of this thesis would like to think about TQM as an evolving process, hence TQM is defined as:

> *"...an evolving process characterized by increased customer satisfaction through continuous improvement, in which all employees in the firm actively participate."*

TQM	
Theory	Focus on the customers
Process view	Improve and uniform processes
Methodology	Plan, Do, Study, Act
Approach	Let everybody be committed
Tools	Analytical and statistical tools
Primary effects	Increased customer satisfaction

Table 1: A short presentation of TQM (Andersson & Eriksson, 2006).

Being able to evaluate the possible benefits from TQM is crucial and many different approaches exist. Historically, one of the commonly used methods to quantify the benefits of quality has been to calculate the costs of poor quality (Silveira & Borenstein, 2000). One important factor seems to be that it should be possible to measure how much a TQM system is affecting an organization. Later research has shown that a successful TQM implementation has a significantly positive impact on the organization's operating results, which should imply satisfied owners as well as customers (Andersson & Fornell, 1994). Other studies show results of increased customer satisfaction, better employee relations, improved internal procedures, and increased profitability (GAO, 1991).

3.4.3 TQM Methodology

There is no dominating and generelly accepted TQM theory existing, it has yet to be developed (Sila & Ebrahimpour, 2000). The quality guru Edward Deming was perhaps the first to make an attempt with his framwork, *14 points*, published in the famous book *Out of the crisis* (Deming, 1988). Recently, Anupam & Swierczek continued the search for a TQM methodology and through a conceptual empirical research and a thorough literature review they presented ten constructors that firms could follow striving to sucessfully implement TQM (Anupam & Swierczek, 2008). These ten constructors can be found below in Table 2 and the constructors are thereafter briefly described.

The ten constructors of TQM
1. **Top management commitment**
2. **Supplier quality management**
3. **Continuous quality improvement**
4. **Product innovation**
5. **Benchmarking**
6. **Employee involvement**
7. **Reward and recognition**
8. **Education and training**
9. **Customer focus**
10. **Product quality**

Table 2: The ten constructors of TQM (Anupam & Swierczek, 2008).

1. Top Management Commitment

Providing leadership from top management when implementing TQM has proved to be one of the major key success factors. The management must be involved and committed, creating goals, values and visions. (Brown & Hitchcock, 1994) Further, Brown & Hitchcock conclude that the lack of top management commitment is one of the main reasons organizations fail to adopt TQM. The top management should provide the employees with quality roadmaps and encourage the involvement in the TQM efforts (Anupam & Swierczek, 2008).

2. Supplier Quality Management
It is essential for manufacturing organizations to have a constant supply of high quality raw materials. The quality of the final product is greatly affected by the quality of the material delivered by the supplier and poor quality will inevitably result in higher costs for the manufacturing firm. Establishing a long term relationship with suppliers is an appropriate method making it possible for the purchasing firm to lower the quality inspection costs and ensure a continuous supply of high quality raw material. (Juran & Gryna, 1993)

3. Continuous Quality Improvement
To achieve a continuous quality improvement, the existing quality and management processes need to be evaluated (Juran & Gryna, 1993). The next step for the organization is to collect necessary quality data as a routine, measuring the size of the quality issues and settling the cost of poor quality. The gathering of the quality data and the establishment of quality key indicators will help evaluating the quality management practices. Suitable methods to use are quality control tools, inspections, and sampling. (Anupam & Swierczek, 2008)

4. Product Innovation
The firm's product innovation must consider the customer requirements and involve various representatives from different parts of the organization in cross functional teams (Kumar & Gupta, 1991). It is essential to fulfill or exceed the customers' expectations on the product. The product innovation should translate the customer needs into product specifications using tools like, for example, quality function deployment. The upcoming product designs need a thorough evaluation before entering the production line to avoid manufacturing problems. (Anupam & Swierczek, 2008)

5. Benchmarking
It is crucial for firms to continuously benchmark existing products and services to other organizations. By comparing processes and products attributes with leading firms in the same industry or with firms in other industries, the company can improve the overall quality performance and meet the specifications required by the customers. (Goetsch & Davis, 2003)

6. Employee Involvement
A firm should generate a system that will encourage and reward employees to participate in ongoing quality improvement processes. The management must communicate the benefits with improved quality to the staff and together forge the quality framework to prevent the not-invented-here syndrome. By doing this, the employees will feel responsible and involved in the change process and create a commitment to the quality concerns. (Anupam & Swierczek, 2008) Creating quality circles or quality improvement teams are other tools to help improve the quality (Kumar & Gupta, 1991).

7. Reward and Recognition
Firms can improve the quality performance by giving employees recognition and rewards for good work or by rewarding innovative suggestions that helps improve the product quality. Rewards can be given to individuals as well as departments, and could include higher salary but also non-monetary rewards as promotion. Thus, the company should develop a rewarding system with the objective to encourage employees to actively improve product quality. (Anupam & Swierczek, 2008)

8. Education and Training
To achieve a successful TQM implementation, education and training of the employees are an important factor. The quality education should make employees understand the importance of issues regarding quality and provide them with tools and techniques to solve existing problems. By viewing employee quality education as an investment and not a cost, the organization can develop an environment where the employees and the managers together will be involved in the quality changes. (Anupam & Swierczek, 2008)

9. Customer Focus

When using TQM, it is vital to incorporate the customer in the production process. The firm should manufacture products that satisfy customer needs and a build a close relationship with the customer. Organization should be able to respond quickly if the customer specifications are changing and strive to implement customer input in the product design and development process. By doing this, the firm will gain valuable feedback continuously and the new product attributes will more likely improve the customer satisfaction. (Anupam & Swierczek, 2008)

10. Product Quality

If a firm wants to achieve a higher product quality it is required to fully understand the impact of the quality problems. Thereafter the company needs to start continuously collecting data and measure product quality. While doing this, the management can fully grasp the amplitude of the quality issues and start making efforts to enhance the product quality. (Anupam & Swierczek, 2008)

3.4.4 Criticism of TQM

Andersson and Eriksson (2006) state that; *"Attempting to define TQM is like shooting at a moving target."* The fact remains that it is hard to properly define TQM, which some critics argue is the main reason why many organizations fail to implement TQM effectively (Eskildson, 1994). Although there are various examples of organizations improving substantially implementing TQM, there are also several examples of firms that did not. Conducted research concludes that only one of three firms at best have achieved tangible results regarding product quality while implementing TQM (Harari, 1997).

Further, the management must realize that the implementation of the TQM process takes a lot of time and efforts and that implementing TQM is not an easy task (Dahlgaard & Dahlgaard-Park, 2006). Dettmer (1995) argues that since TQM focus on measuring, it has the ability to make firms "metric crazy". If the management does not know how to extract relevant information from the collected data, it is obviously only a waste of time and money. But if the circumstances are right and there is emotional involvement and a strong internal motivation among both management and employees, TQM could doubtless be a powerful method to enhance a firm's product quality.

4 Tailor Store – The Case Study Company

4.1 Chapter Overview

Chapter 4 primarily serves as a presentation of the case study company Tailor Store International, focusing on TSI's production. The chapter is mainly based on empirical data but a small analysis is also included and serves the purpose of pinpointing Tailor Store in the mass customization spectrum. Initially, a background of the case study objects, TSS and TSI is given. Details for the manufacturing plant's production setup are included, followed by a review of TSI's current quality routines. Finally, some of the current problems facing the two companies are concluded. When using the name Tailor Store in the coming sections and chapters, both TSS and TSI are concerned.

4.2 Tailor Store Sweden (TSS)

Tailor Store Sweden AB (TSS) is small sized e-commerce clothing company located in Helsingborg, Sweden. The company was founded in 2003 and the main business concept is to market and sell custom made garments online at their website[2], to a broad mass of private consumers (Höjman, 2008). TSS imports customized dress shirts from the independent sister company Tailor Store International (TSI), located in Sri Lanka. TSS mainly focuses on marketing, product development, distribution and customer service (Loodberg, 2008). The firm presently has six full-time employees, and in 2006-2007 TSS had a net turnover of approximately 1.5 million USD. The majority of TSS customers are located in Scandinavia. However, within a short future, TSS aims to capture larger market shares in particularly UK, France and Germany. The company is expanding rapidly and the vision is to be the obvious choice for online shopping of made-to-measure wear, quality clothing and accessories. (Ström, 2008) In 2006, TSS was acknowledged with the SIME award "best e-commerce company in Scandinavia" (SIME, 2008).

4.3 Tailor Store International (TSI)

Tailor Store International Pvt Ltd (TSI) is a manufacturer of apparel clothing and the firm specializes in the production of customized dress shirts. The company is a young business located in Sri Lanka. The company acquired its first large-scale production facility during 2007, located on the Sri Lankan countryside. TSI is a medium sized growth company with a present workforce of 200 employees. The core business concept is to manufacture customized shirts and the production facility is equipped to manage batches of single shirts. In the nearby future, TSI is planning to expand the production capacity of the manufacturing plant. (Nalin, 2008)

4.4 Interaction between TSS and TSI

The end customer purchases products through TSS's website, which provides the customer with the possibility to customize and design the shirt at different preferred customization levels. Possible customer inputs are individual measurements, selection of fabric, and different styles of shirt design. The majority of the customers pay TSS in advance for the product, and when the order is placed the order is moved to a production queue. When the order is about to enter production TSS generates a printout containing all available facts about the customer's selections. This printout is sent from TSS to TSI who launches the production of the order. The shirts are thereafter sent back to TSS, who manages final distribution to the end customers. A current problem for TSI is the lack of direct customer feedback. TSI's link to the customer requirements is primarily given through the printouts provided by TSS. (Loodberg, 2008).

[2] www.tailorstore.com

4.5 Defining Tailor Store's Level of Mass Customization

The business strategy jointly adopted by TSS and TSI is mass customization. The core products are tailored shirts, and the customer selections are realized during the design phase, before the shirt enters the production line (Shyamalie, 2008). Accordingly, Tailor Store can be labeled as a fabricator using Duray's (2002) classification matrix. This is true considering that the firm involves the customer in the early design phase, when the largest changes of functionality and design yet are possible. Hence, TSI utilizes a strategy with a high degree of customization, but the company is also striving to gain the scale advantages of a mass production strategy. Viewing TSI through Gilmore and Pines framework (1997), the customization level can be viewed as a collaborative customization. A collaborative customizer is aiming to create an ongoing dialogue with the customer, facilitating the customer to express their explicit needs. TSS's website offers customers the possibility to create an individual design of the shirt and thus Tailor Store can be considered a collaborative customizer. Gilmore and Pine emphasize the good fit between a design business and the level of a collaborative customization. One can further argue that the level of customization is a mix between collaborative and adaptive customization. Hence, an adaptive customization is when a firm offers a standard product which can be altered by the customer to fit specific customer needs. As mentioned before, the standard products provided by TSI are a shirt, and TSS provides customers with the possibility to adjust and customize this standard product. Aiming to pinpoint Tailor Store on the mass customization map, the firms are considered a merger of fabricators utilizing a mix of collaborative and adaptive customization. This is considered to be a high level of customization and is likely to have implications on the production.

4.6 TSI Production Setup

Before turning focus to TSI's production challenges, the reader will be given a brief introduction to the production setup. During TSI's expansion, the production setup has been altered several times. The firm has moved from employing traditional tailors who singlehandedly stitch a complete shirt, to a line system divided into several production steps. The line system is composed of 25 production operations which are subsets to the eight production sections detailed below. In the beginning of 2008, the line system was modified to include stitching teams. The teams can simply be considered as a number of assembly lines equipped with the minimal workforce required to efficiently produce a shirt. (Nalin, 2008)

A brief description of the eight main production sections follows. The data was collected through observations and a set of interviews with Shyamalie, Production and Communication manager in TSI. It is important to notice that all of these production steps are sequentially dependent. A random production step cannot be realized before the previous steps are conducted. Preparatory work can thus not be completed by production sections later in the line.

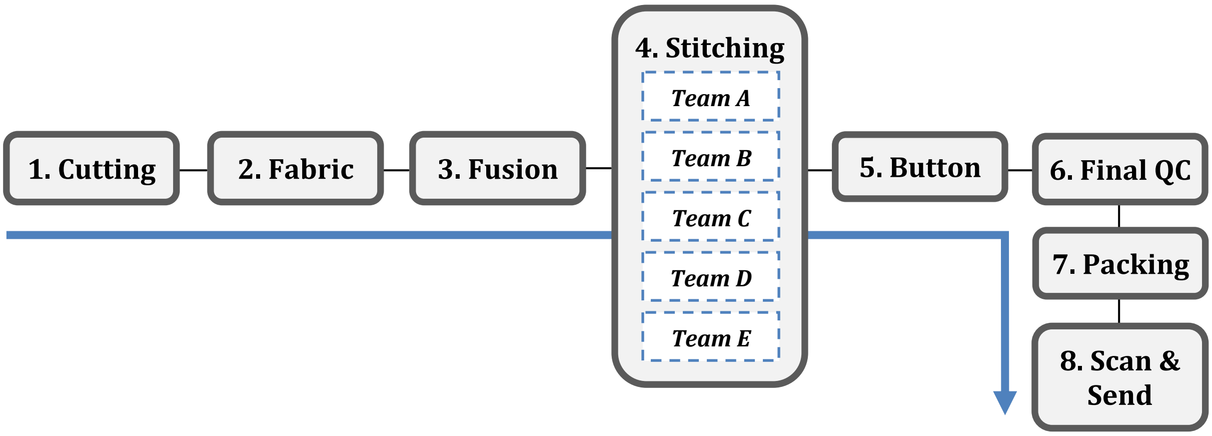

Figure 9: Schematic illustration of TSI's production.

1. *The cutting section* prepares shirt pieces for the following production steps. The cutters get the selected fabric delivered to their cutting table by a production helper. The cutting of a shirt is thereafter performed manually with a pair of scissors. A great deal of the cutting is based on the individual knowledge and skill of the employee, and the cutting section holds the most experienced employees in the TSI production line.

2. *The fabric quality control section* guarantees the quality of the fabric by reviewing every single piece of an unmanufactured shirt. If damaged fabric is discovered the concerned piece will be cut all over again by the cutting section.

3. *The fusion section* contains fusing machines which is processing specific parts of a shirt. The employees working in the section are preparing selected parts of the shirt, e.g. the collar and the cuffs, with fusion material to ensure that the fabric becomes stiffer.

4. *The stitching teams* work as five small lines within the main line system. Each of the five teams contains fifteen machine operators who are stitching the different parts of the shirts with sewing machines. The stitching of a shirt is divided into ten specific and dependent operations. All teams have a team leader who is responsible of managing and supervising the team.

5. *The button section* employs a total of thirteen workers. The main task is to mark and produce the button holes and attach buttons to the shirt. The button holes and the attachment of buttons are performed by machines run by an operator. Manual operations such as button hole clearing and extra button attachment are also conducted at this section.

6. *The final quality control section* has the objective to ensure that the processed shirts have a satisfying, high quality level, including good stitching, cleanness and correct measurements. There are thirteen employees working as quality controllers. Shirts that are rejected are sent back to the responsible selection in the line to be corrected.

7. *The packing section* is ironing the shirt and wrapping it into plastic. The section has eight employees.

8. *The scan and send section*, is responsible of scanning the printout into the local IT-system and ensure that each customer order containing several product is packaged together. The shirts are placed into boxes which are weekly delivered by air cargo to TSS.

4.6.1 Stitching Team Setup

The setup of a standard stitching team in TSI is displayed in Figure 10. Each operation has one operator working manually with a sewing machine. Due to different process times of a shirt, the stitching team has a varying number of operators performing each operation. For example, station one, seven, and eight all have a relatively long process time of a shirt, and therefore have three operators each in the regular TSI stitching team. Stations number three and nine are specific for ladies shirts and are not performed in the stitching teams. Notable is also the team leader, who is responsible for the team output and of product quality.

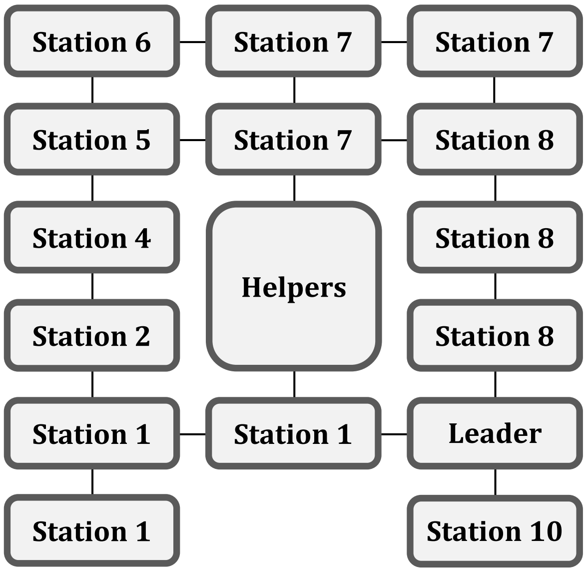

Figure 10: Example of stitching team setup.

4.7 Quality at TSI

Product quality is regarded as a crucial matter at TSI (Priyantha, 2008). Although the production management is aware of the importance of product quality, supervisors confirm that TSI most likely has product quality issues (Ganesan, 2008).

The present quality assurance policy enhanced by TSI does not employ a quality system or quality guidelines for the production. Most of the knowledge about product quality is embedded in employee knowledge. The organization is struggling to clearly define the meaning of good product quality. As a consequence of the latter TSI faces challenges when incorporating new employees in the organization. When new employees start working for TSI, the problems with product quality tend to become a growing issue. (Shyamalie, 2008)

The most important quality characteristics at TSI are considered to be the measurements and the overall appearance of a shirt. Since TSI business model is based on production of individually customized shirts, the measurements are specific for each customer. Hence, the most crucial product quality characteristic for TSI is correct measurement, which if correct will ensure that the customized shirt will have a good fit for the customer. The second most important factor is the overall appearance of the shirt, including characteristics like high quality fabric and well performed stitching. TSI has a monthly meeting where the management advises and educates the employees about the importance of quality. Further, experienced staffs in the work force daily help beginners to learn about the quality standards of TSI. (Priyantha, 2008)

TSI emphasizes the importance of customer satisfaction when defining product quality. The goal for the company is to consider customers' preferences and requests regarding product quality. The printout is the main input of customer needs in the production process. The fact that the printout is the only customer input sometimes makes it difficult for the firm to fully grasp how the customer values product quality. (Ganesan, 2008)

4.7.1 Shirt Damages

There are numerous damages which will imply that a shirt has to be remade. Some of the most common errors are machine damage, poor stitching, and overall damages affecting the total appearance. The latter can e.g. mean incorrect placement of a pocket or an erroneous shaped collar. The fact that employees sometimes do not consider the printout correctly can result in various product errors such as poor measurements, selection of incorrect fabric, or wrong type of shirt cuffs. (Priyantha, 2008)

Most of the damages occur in the stitching teams, and to reduce those damages it is important to continuously call attention to the responsible operator (Ganesan, 2008). This method of learning is complicated by the fact that there is no established quality framework at TSI, which means that the staff member responsible for quality control sometimes have different comprehensions of how to define high quality.

4.7.2 Quality Control

TSI has two quality checking stations in the production line; (1) Fabric Control, and (2) Final Quality Control (Nalin, 2008).

4.7.2.1 Fabric Control

The fabric control section is located after the cutting section in the production line. The workers manually check each piece of garment produced by the cutting section to ensure that no fabric damage exists on the garment pieces. A potential damage of the fabric which is discovered later on in the production line implies a great time waste, since the shirt most likely will have to be unstitched and remade. The existing suppliers guarantee high quality fabric but TSI has still chosen to perform a re-check due to earlier problems with poor fabric quality. (Shiroma, 2008)

4.7.2.1 Final Quality Control

The last quality checkpoint in the TSI production line is the final quality control, which is located after the button section and prior to the packing section. The final quality controllers are personally responsible for not letting any damaged shirt pass. Every shirt is thoroughly evaluated by a final quality checker before entering the packaging section, which means that TSI do not use random sampling in the quality control. Every batch is examined and since the production line only has batch-sizes-of-one every single shirt requires supervision.

4.8 TSI Problem Discussion

During recurring periods, TSI has encountered problems with increasing manufacturing lead times. Throughout 2008, the manufacturing plant has been able to produce an average of 150 shirts per day, normalized to an eight hour workday, seven days a week. However, the throughput is a major issue because the demand from the market and TSS has occasionally reached 200 shirts per day during the same time period. Consequently, the manufacturing plant has suffered a daily lack of 50 shirts, which has resulted in a growing queue of shirts waiting to enter TSI's production line. (Nalin, 2008) An increased queue implies a higher total lead time for each product. This is a serious dilemma for TSI and TSS, since it causes the customers increased waiting time. Both TSS and TSI agree on that an increased lead time will cause immediate customer dissatisfaction. TSS emphasizes that customers highly value a short lead time (Loodberg, 2008). The problems in the production of TSI accelerate when the demand for shirts increase (Shyamalie, 2008).

According to TSS's enterprise system, the manufacturing lead time has averaged 10 days (including weekends) the recent months. The average work in process amount to approximately 1500 shirts and the average throughput is 150 shirts per day. These production figures correspond well with a theoretical approximation. When applying Little's law, an average manufacturing lead time of 10 days is obtained, when using the figures 1500 shirts in WIP and a throughput of 150.

Besides the WIP of 1500 shirts, the queue prior to the production consists of an average of 1500 shirts. TSI is liable for the total amount of unproduced shirts which constitutes a major part of the total lead time. A total of 3000 shirts is equivalent to approximately 20 days manufacturing lead time which roughly constitutes 2/3 of the total lead time. Hence, it is crucial for TSI to shorten the manufacturing lead time while simultaneously increasing or maintaining the throughput.

Figure 11: A system approach disclosing the TSI production as the total system's bottleneck.

By perceiving TSI's production, TSS marketing/sales division, and the customer/market demand as a TOC-system, the entire systems constraint can be identified. The system consists of three dependent variables, with varying capacity/demand. TSS is estimating the current market demand to be approximately 300 shirts on a daily basis and has not yet managed to meet this demand. Instead, TSS sales division is receiving a daily average of 200 customer orders, during a certain time period. However, during the same time period, TSI has had difficulties reaching this number, and only been able to produce a daily average of 150 shirts. Hence, TSI's production becomes the constraint or the bottleneck of the complete system. The first concern using the TOC methodology is to identify the bottleneck, and thereafter, the next step is to exploit or strengthen the constraint. Consequently, the adequate approach using TOC would be to attack the system constraint, which in this case is TSI's production.

5 The TOC process at TSI

5.1 Chapter overview

Having identified the production as the total system constraint, the next logical step is to make a deeper analysis of the problems stated in chapter 4. To achieve this, the TOC process is applied on TSI's production with the intention to identify the constraints and then strengthen them. To fulfill this purpose the five step improvement process of TOC is utilized on TSI's production. A change of the ordinary order of the steps in the TOC process has been realized. Step 3, subordinate everything to the constraints, and step 4, elevate the constraint has switched places in the process. This is simply done to facilitate the understanding of the process and the results. Below follows a short summary of the process and how it is adjusted for TSI:

Step 1 – Identify the constraint(s): To localize the bottleneck a complete mapping of the production is conducted. Information is gathered using several methods and sources to ensure that the true constraints are identified.

Step 2 – Exploit the constraint(s): The next step is to exploit and strengthen the identified constraints. Two different types of bottlenecks are approached with focus placed on the nonconventional constraint.

Step 3 – Elevate the constraint(s): No concrete actions were taken in this step, instead, a short reasoning is held, explaining what future actions TSI could take to elevate constraints.

Step 4 – Subordinate everything to the constraint(s): To ensure that the constraint operates optimally the complete system needs to be aware of the constraint to avoid unnecessary disruptions. Measures to create awareness of the constraint and ensuring an undisturbed flow of WIP to the bottlenecks are taken.

Step 5 – Repeat the process: A short discussion will be given concerning how to continue the initiated TOC process at TSI.

5.2 Step 1 – Identify the Constraint(s)

5.2.1 Chapter Overview – How to Find a Bottleneck

Recognizing systems constraints can be accomplished in several different ways. A total of five different procedures where established for this research. Inspiration to these methods was found in *the Goal* (1984), where a similar procedure is used to identify the production constraints. The fifth method used to localize constraints, the quality study, is not available in the book. This step was derived from the results of the previous techniques. Here follows a brief overview of the five methods used:

1. **Capacity study** – Establish the theoretical capacity for each production section and compare it with the market demand placed on them. The capacity study will reveal process times and variance for each production step. If the capacity of a station is equal to or less than the market demand the section is considered as a potential bottlenecks.
2. **Work in Process (WIP) study** – A large stock of WIP or inventory waiting to be processed indicates a potential bottleneck. This means that the section has not been able to process products in the same pace as the previous section in the production line and is therefore classified as a potential bottleneck.
3. **Production data study** – Gathering historical production data for each production section could contribute to exposing the systems bottlenecks. The collected data is used as a complement to the capacity study, aiming at identifying low capacity sections that are potential constraints.
4. **Employee interviews** – Knowledge and experience regarding the production from employees and managers can contribute to finding production bottlenecks.
5. **Product quality study** – The quality study will reveal if quality concerns at a specific section could cause a bottleneck.

Each of these measures provides a different angle or perspective to the task of exposing the TSI system constraints. By relaying on a wide set of methods the potential risk of not finding the true bottleneck is minimized. Consider the risk of simply relaying on the methods of historic production data and employee experience to find the constraint. These two methods will most likely not take dependency into consideration and will therefore probably fail to distinguish the actual bottlenecks from subsequent production steps that might hold a higher production capacity, but are limited by its previous production unit. In the same way capacity studies and queue measurements needs to be complemented with actual production data and employee experience.

5.2.2 Capacity Study

The first data collected to indicate the location of potential bottlenecks are production process times. By conducting measurements for each production unit, an average process time for each system component is established. When multiplying the process time for each production operation with the number of workers or machines involved in a specific operation the capacity is obtained. It should be noted that the daily capacity is normalized to an 8-hour work day. The study was conducted for all 25 production steps and a summary of the study is available in Table 3.

The study clearly shows that there are big differences among the production steps when considering theoretical capacity. Some production units are capable of producing over 300 shirts (packing, scan and send) while other barely exceed 150 (placket fusion, cutting of placket). As mentioned previously, 150 shirts is the average daily output from TSI’s production. Clearly, the total production output is tied to the production sections with the lowest capacity, precisely as TOC states. Another conclusion to be drawn from the figures presented in the table is that some production sections house overcapacity. This implies that these sections will unavoidably be idle at certain points. Naturally, this fact will result in various consequences. An obvious drawback is the increased operational expense carried by redundant workers. But the effects are far from solely negative. Overcapacity will, in a higher extent, guarantee that the production runs without disruptions. Consider absentees for instance, excess workers are suitable when covering for non-attendance.

Number	Sections	Process Time	Setup Time	Standard Deviation	Daily Output Capacity
1	Cutting	26.12	1.25	8.08	193
2	Collar cutting	4.58	0.50	2.18	284
3	Fabric quality control	6.92	1.00	8.48	242
4	Ironing	7.55	0.50	2.98	298
5	Fusion	2.69	0.50	0.48	180
6	Cutting of placket	2.34	0.50	0.71	169
7	Placket fusion	2.66	0.50	0.58	162
8	Cuff drawing	2.28	0.50	1.19	346
9	Station 1	23.22	1.50	16.78	350
10	Station 2	12.33	1.50	2.44	243
11	Station 4	10.25	1.50	1.79	204
12	Station 5	9.23	1.50	6.48	268
13	Station 6	3.64	1.75	2.37	267
14	Station 7	22.47	1.50	7.33	260
15	Station 8	25.40	1.50	5.75	286
16	Station 10	6.63	1.50	2.92	295
17	In line QC	8.93	1.00	3.00	241
18	Button hole	4.35	2.00	1.20	189
19	Extra button	2.87	0.50	0.62	285
20	Button hole clear	5.55	0.50	1.88	238
21	Button mark	3.10	0.50	1.10	266
22	Button attach	3.05	2.00	1.08	238
23	Final quality control	13.72	0.50	3.75	270
24	Packing	11.86	0.50	2.51	311
25	Scan and send	1.35	0.25	0.63	600

Table 3: Daily capacity for each production unit at TSI.

Table 3 also presents the standard deviation for each production section. The standard deviation reveals on average how far the process time varies from the mean process time. When conducting the study, some values were found to be closer to the mean value and other further away from it. Some operations display a high standard deviation in relation to the average process time. This indicates large fluctuations in the collected data. Studying the results in the above table, the sections with the highest standard deviation are Cutting, Fabric Control, Station 1, Station 5 and station 7. The source of the high standard deviation considering Cutting and Fabric Control is mainly caused by different skilled and experienced workers, performing the operations with varying speed. On the contrary, the high standard deviation found in Station 1, Station 5 and Station 7 is mainly caused by varying product features. This is true considering that the current stations have the most varying product features of all the different sections in TSI's production line.

A production unit with high variation should be approached with caution, especially if it poses as a potential bottleneck. Variation can cause the production sections to temporarily operate below the average capacity and if not governed properly it may cause bottlenecks to stand still.

The capacity study reveals several potential bottleneck candidates. Recall the definition of a bottleneck. A bottleneck is equal to or less than demand placed upon it. The demand currently placed on each production unit is considered approximately 200, which simply is the average daily order flow provided by TSS. With this in mind it is easy to narrow down the results from this study to the following potential bottleneck sections:

- Cutting section, (capacity of 193 shirts/day)
- Fusion, (capacity of 180 shirts/day)
- Cutting of Placket, (capacity of 169 shirts/day)
- Placket fusion, (capacity of 162 shirts/day)
- Station 4 in the stitching teams (capacity of 204 shirts/day)
- Button Hole, (capacity of 189 shirts/day)

Even though the sections cutting of placket and placket fusion displays a low average capacity, the sections will not be considered as possible constraints. The TSI management confirms that these sections are unlikely to be bottlenecks (Shiroma, Shyamalie, Priantha, 2008). Also, later measurements such as the WIP study confirms that these sections are not bottleneck. The authors believe that some measurement error has occurred. With this said the indicated problem areas from this study are: (1) cutting section, (2) fusion (3) stitching operation 4, and (4) button hole.

5.2.3 WIP Study

The next step is to examine queues of WIP for each production step. The operations with the largest inventory are likely bottleneck candidates. When referring to WIP or inventory in this chapter unfinished shirts, waiting to be processed are considered. Table 4 displays a summary of the WIP for the main sections in the production. The stock of WIP that is larger than 75 are marked bold to highlight potential problem areas.

Most of the production sections listed in Table 4 consist of several additional operations. The WIP number displayed for the main production section is actually constituted by several smaller operations. Measurements were made individually for each of these production resources, but to simplify the illustration, the presentation of the results is grouped together.

The problem of finding the bottlenecks is initially approached by examining the average queues for each section. Table 4 shows that the largest number of shirts is located in the stitching teams, at the button section, and at the quality control section. A quick comparison of the capacity for each of these sections in Table 3 provides contradicting indications. The sections with low capacity should reasonably be the production components that contain the highest inventory but this is not validated by the WIP study. For instance, all stitching stations have a capacity that exceeds 200 shirts per day; hence large inventory should not need to arise. The same reasoning applies for the two other sections, button and quality control. According to the capacity study, a potential bottleneck is located at the fusion section but only insignificant WIP stocks are observed here. Based on this simple comparison it becomes clear that the capacity and inventory study are not sufficient to determine the systems constraints. To be able to draw further conclusions and understand why the two studies indicate different bottlenecks further profound studies are required.

# of days	Cut shirts	Fusion	Team A	Team B	Team C	Team D	Team E	Button	Final QC	Packing
1	0	0	63	0	0	0	65	0	0	20
2	67	39	54	66	50	**96**	60	**171**	63	15
3	**84**	28	71	**92**	32	**93**	62	**125**	0	**119**
4	**161**	69	62	57	31	**93**	66	**151**	14	**103**
5	**184**	53	58	**78**	40	**79**	71	**169**	11	**86**
6	**93**	29	0	62	41	**93**	71	**157**	49	73
7	**122**	23	60	57	45	**96**	57	**142**	72	44
8	**119**	9	54	59	46	**98**	**76**	**139**	66	25
9	49	13	70	**80**	42	**86**	67	**113**	10	28
10	50	31	62	75	43	67	65	**161**	58	29
11	51	20	58	**79**	42	63	65	**152**	68	17
12	36	12	66	**88**	41	70	65	**144**	**89**	0
13	**96**	31	56	69	40	**77**	62	**145**	**88**	22
14	**77**	14	64	57	36	60	**80**	**121**	**116**	28
15	71	22	46	48	36	55	74	**178**	**92**	39
16	45	14	52	70	44	53	38	**191**	**114**	14
17	28	13	46	**87**	37	29	72	**172**	**130**	14
18	20	14	57	**85**	37	29	**78**	**148**	**80**	2
19	51	16	47	42	37	56	**78**	**152**	**105**	3
20	46	21	59	38	39	18	**78**	**138**	**107**	3
21	40	16	44	37	47	29	75	**144**	**141**	0
22	0	19	38	61	43	28	**85**	**169**	**188**	0
23	9	22	44	63	39	30	**81**	**133**	**239**	13
24	1	11	37	67	45	19	**86**	**120**	**158**	3
25	3	13	45	65	67	37	**91**	**118**	**227**	**79**
26	5	24	45	56	72	38	**91**	**100**	**247**	51
27	38	14	36	54	**88**	27	**99**	**92**	**193**	15
28	39	21	40	66	**92**	26	**101**	**109**	**167**	25
29	14	24	42	58	**85**	32	**97**	64	**153**	42
30	41	23	24	54	**99**	27	**95**	41	**167**	38
31	74	15	58	34	66	30	**92**	**85**	**183**	49
32	49	25	53	34	53	16	**91**	66	**154**	41
33	40	23	47	37	48	17	**101**	88	**183**	38
Avg:	**45**	**19**	**50**	**60**	**52**	**45**	**79**	**127**	**133**	**25**

Table 4: Inventory overview for the main production sections.

Before continuing with identifying the bottlenecks some important production characteristics related to inventory will be brought into the discussion. Firstly, a large number of WIP evenly scattered across the production makes it harder to quickly retain an overview of where the constraint problem lies. Secondly, high inventories spread evenly across the production could result in concluding that bottlenecks will only have limited effect on the system. But why is this? WIP is actually synonymous to a safety backup. It provides the production section with access to unfinished products/shirts if the flow from the preceding step is throttled. A reserve available throughout the entire production system should minimize the risk of suffering from a bottleneck limiting the throughput of the system – or? While this is partially true a high work in process will not single handedly guarantee that a system is protected from the effects of a bottleneck.

During the studied period high inventories are located in different sections in the production line. These unexpected high levels of inventory are likely caused by some type of variation and are for instance observed at the stock of cut shirts and at the packing section, see first rows of Table 4. If variation is able to cause a temporarily high inventory it should also be capable of draining it and cause part of the system to idle if not properly monitored. Indications of this are also observed in Table 4. Study the two last columns of Table 4 between row 18 and 24. During this period the packing section, which is the final production step, has a low level of inventory while the prior section, final quality control, has a large inventory. The high level of inventory at the quality station indicates some kind of problem whereas packing's low inventories indicate that they from time to time probably will be idle, waiting for shirts. Since packing is last in line there is a possibility that throughput was temporary limited during this time period.

The discussion indicates that a vast and mobile WIP complicates the ability to draw conclusions concerning the effect of the bottlenecks explicitly based on inventories. The WIP study indicates no obvious bottleneck and the shifting inventory levels points towards bottlenecks with a tendency to move. Further, the moving bottlenecks indicate a production subjected to extensive variation. The discussion is left open for now and will be resumed later on.

Even though the studied environment is considered complex and ambiguous, the WIP study concludes the following sections; (1) stitching teams, (2) button section and (3) final quality control section to be the most likely bottleneck candidates.

5.2.4 Production Data Study

Next step in identifying the production system constraints relates to examining historic production data provided by TSI. A period of two months where studied and the data for this time period is made available for the reader in Appendix 3 – Production Data, page 75. A production with a bottleneck located close to the end of the production line will display a capacity curve similar to the left graph in Figure 12, while a bottleneck located at the beginning of the production line will have a curve resembling the right graph.

When analyzing and plotting the data from the two month period, a curve matching the right graph is attained. This indicates that a bottleneck is located at the start of the production line. This is most likely correct or the capacity of the line is in perfect balance. A review of the capacity study in Table 3 exhibits capacity values that exceed 300 shirts for certain stations. These figures are in fact twice as large as the actual output from the first section cutting during the studied two month period (see Appendix 3 – Production Data). This indicates that the cutting section is limiting at least some subsequent sections and is thus identified as a possible bottleneck. A second review of the production data shows that the average output from each section is extremely close to the output from the cutting section which also confirms this suspicion. Some values are actually higher than the output from cutting. This is certainly not correct since dependency implies that subsequent sections cannot output more than the preceding ones. This concludes that there are small errors in the provided data, most likely caused by factory employees reporting incorrect figures to their responsible supervisor. Despite these problems the historical production data clearly indicates that the most likely bottleneck is the cutting section.

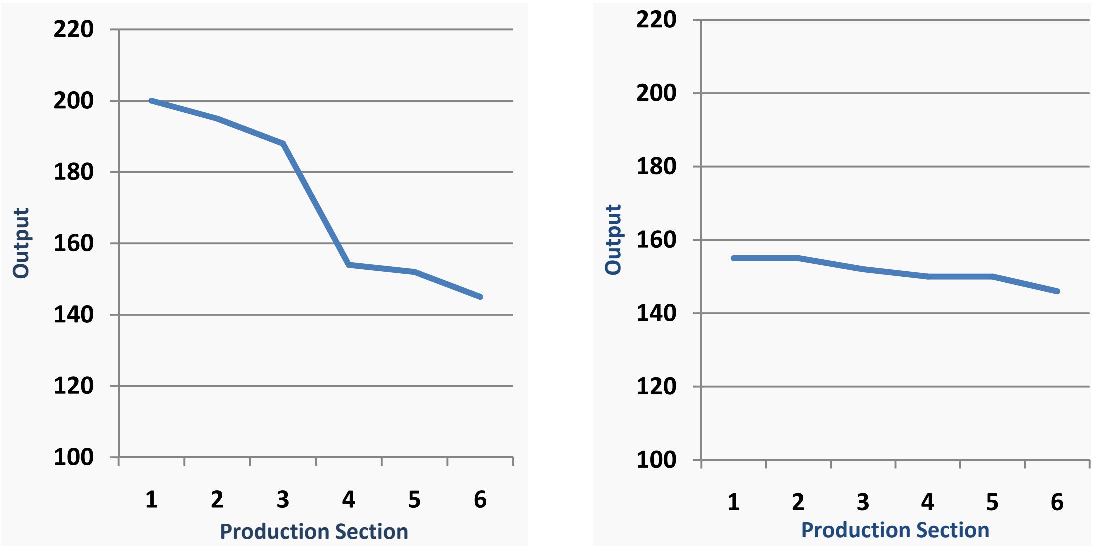

Figure 12: The left graph displays a bottleneck located closer to the end of the production while the right graph has a bottleneck placed at the beginning of the production line.

5.2.5 Employee Interviews

To ensure that the employee knowledge and experience are not neglected, in the search for potential production constraints, experienced employees from TSI are consulted.

Shirt cutting is considered as the most difficult production step and requires experienced tailors (Nalin, 2008). When asked if CEO Nalin, believes that cutting could be a bottleneck he explains that as long as all cutters are present they have no problem providing the production line with sufficient shirt material. But finding a replacement for an absent cutter is often a problem since the knowledge and skill required is a scarce resource for TSI. Absent shirt cutters are a reasonable explanation to why the actual output of 155 shirts does not correspond to the capacity study which indicates an expected daily average output of 193 shirts.

A different aspect is brought to attention by the general manager of TSI, Shiroma, who explains that quality problems have been a reoccurring concern in the production. During certain periods, a high amount of produced shirts have been rejected and sent back to the production. According to the experience of Shiroma, roughly all quality concerns are caused by the stitching teams. Remade shirts imply that the stitching teams are losing capacity since time that could be used to assemble new shirts is wasted on remaking rejected shirts. If the quality problems are of the magnitude that

Shiroma describes, they might reduce the capacity of the stitching teams to the extent that they limit the total production. Turning the attention back to Table 4, page 43, strengthens the assumption about quality problems affecting the output since the stitching teams and the quality section together have the highest average stock of inventory in the production. To fully understand the impact of quality concerns, a detailed quality study is required.

5.2.6 Product Quality Study

A quality review conducted at the final quality control shows that the average rejection rate from the different teams was as high as 38 percent, see Table 5. The quality study was executed during nine working days in February 2008, and the findings from the survey reveal that TSI has serious product quality issues. Almost four out of ten controlled shirts need to be brought back in the line system and be remade. The high level of rejection indicated that TSI is wasting a lot of capacity remaking bad quality shirts and besides this quality concerns could cause certain stitching stations to become a bottleneck. The survey also indicates a high level of fluctuation between the different stitching teams. The best team, Team A, has a rejection rate of 23.2 percent while the team with highest level of quality issues, Team E, had a rejection rate of 58.8 percent.

Even though the quality study reveals that TSI has a high amount of rejected shirts, it is difficult to identify how much capacity that is actually lost. The conducted study measures the rate of shirt damages but do not consider the cause of the damage. It is reasonable to assume that different shirt damages might require different work time to be repaired. Hence, the operator might be able to correct some errors in a short time, while some errors will take longer time. For example, to remake an incorrect collar, normally takes the team operator more time than an incorrect sleeve measurement. It is therefore hard to translate how much time and capacity are lost with a certain amount of rejected shirts. Also, some certain type of errors requires more than one operation to be remade which makes it even harder to estimate capacity loss. The management of TSI is strongly convinced that the product quality issues are wasting a lot of time in the stitching teams (Shiroma, 2008). Since it is principally impossible to derive the source of the quality problem from the conducted study, the authors chose to threat the different stitching station as one unit. It is therefore concluded that the stitching teams with high rejection rate are considered as potential constraints.

Feb 2008	Team A	Team B	Team C	Team D	Team E	Total
Shirts Passed (nbr)	202	116	130	171	100	719
Shirts Failed (nbr)	61	107	68	59	143	438
Rejection Rate (%)	23,2 %	48,0 %	34,3 %	25,7 %	58,8 %	38 %

Table 5: Rejection rate for the available teams, Feb 2008.

5.2.7 Summary Step 1 – Identifying the Constraint(s)

To be able to determine and distinguish the true constraints, the results from each step of this section is organized and compared, see Table 6. A total of four different sections have been labeled as potential constraints using the five various methods. The potential bottlenecks are; cutting section, stitching teams, button section and final quality check section.

	Capacity Study	WIP Study	Production Data Study	Employee Interviews	Quality Study
Cutting Section	√	X	√	√	X
Stitching Teams	√	√	X	√	√
Button Section	√	√	X	X	X
Final Quality Check	√	√	X	X	X
√ = Potential bottleneck section X = Non-bottleneck section					

Table 6: Potential constraints identified during step 1 in the TOC-process.

The table clearly indicates two possible problem areas. The authors have chosen to label (1) stitching teams and the (2) cutting section as the systems constraint. Henceforth the TOC-process will focus on these two production sections. Below follows a more detailed description of the selected bottlenecks.

1. Stitching Teams: Four out of five methods used to identify constraints conclude that the stitching teams are potential constraints. If it is possible to improve the overall product quality, or in other words, lower the quality rejection rate, TSI will be able to output a larger number of shirts from the production teams. As discussed earlier, a high rejection rate is causing the stitching teams to remake a large number of shirts. This is an obvious time waste and it lowers the capacity of the stitching teams. If the quality problems are resolved, capacity can be increased which also will allow the throughput to rise. Thus, problems limiting the stitching teams become an immediate issue to solve for TSI. Accordingly, to achieve a higher throughput of shirts, TSI will have to improve the product quality in the stitching teams.

2. Cutting Section: Three out of the five methods used to identify constraints conclude that the cutting section is a potential constraint in TSI's production. The cutting section is an example of a classic production bottleneck with low capacity and a high standard deviation. Another important factor is that the cutting section is the first section in TSI's production line. The historical data shows that the output of the cutting section is limiting the entire production, because the effect of dependency. Thus, if TSI want to achieve higher throughput of shirts it is vital to improve the capacity of the cutting section. However, the problem for TSI is that the cutting of a shirt is a highly difficult task which takes employees a long time to master and shirt cutters are considered a scarce resource for TSI.

5.3 Step 2 – Exploit the Constraint(s)

5.3.1 Chapter Overview

The previous section highlights quality concerns in the stitching teams and the production step cutting as the two most likely system bottlenecks for TSI. The two bottlenecks, stitching teams and cutting sections differ in character but share the limiting effect on the total production system. During the execution phase of this master thesis, the main focus was placed on exploiting the constraint regarding quality in the stitching teams. This decision was taken with agreement from the TSI management. The main focus in this chapter is thus placed on quality improvements in the stitching team. The constraint concerns regarding the cutting section lacks an implementation, and will therefore be devoted a briefer theoretical analysis.

5.3.2 Stitching Teams - Quality Improvement System

The development and implementation of a quality improvement system at TSI was supported by the quality management tool TQM. When implementing the changes to improve the product quality in the selected test team, the TQM methodology provided by Anupam & Swierczek (2008) is utilized. This chapter explains step-by-step how the ten constructors were applied on the selected team, Team C, aiming to improve the product quality. Some constructors were utilized in a larger extent, since they were considered to be well suited for TSI. Other constructors were considered to have less importance to TSI or outside of the scope for this thesis. Those constructors that have not been practically used are instead addressed by providing TSI with recommendations on future implementations.

5.3.3 TQM Utilized in TSI

5.3.3.1 Top Management Commitment

The top management of TSI was committed to the changes early in the process. In fact, it was partly the top management who requested a change process to be initiated. The two conducted management workshops provided the management with an understanding of the TOC process and the existing product quality issues. The top management became involved in the process and participated in generating practical solutions. The fact that the management was very keen to make changes in the production line facilitated the changing process considerable. A possible reason for this is that TSI is a young organization that has a habit of frequently implementing changes. This means that the organizational routines are easier to change and reluctance to perform organizational transformation is lower compared to a more mature organization.

5.3.3.2 Supplier Quality Management

TSI has a supply of fabrics and accessories, e.g. buttons, thread and fusion material. The company is working with several different suppliers, and has had some problems in the past with for example poor fabric quality. The agreements with the fabric suppliers contain a paragraph stating that the supplier is responsible for fabric quality control (Nalin, 2008). If the relation with the supplier is developed, TSI should be able to lower the inspection costs, thus remove the fabric quality control section in the production line. This is considered to be out of scope, and the authors recommend it to be investigated further in the future.

5.3.3.3 Continuous Quality Improvement

TSI’s existing quality process is mainly based on a personal experience and embedded employee knowledge, sometimes referred to as tacit knowledge. If the organization wants to be able to continuously improve quality, the first step is to actually collect quality data and measure the product quality. The course of action was to make sure that the employees at the final quality control continuously documented the different quality rejections and also noted in which section in the production line the damages occurred. Once the data is collected, it must be further processed.

Therefore an IT-module was created and integrated into the local IT-system. The module created was named TSI Rejection Rate Calculator, see 8.1 Appendix 1: TSI Rejection Rate Calculator page 73. The purpose of this tool is to simplify the task of calculating the daily rejection rate and the daily team output. A daily routine to measure the rejection rate and the output of quality approved shirts, on a team basis, was established. The measured data are communicated to the employees on big whiteboards located in the manufacturing plant, and the information is updated every morning.

With quality measurements implemented and available, the second step is to take action on improving the product quality. To create a unified image of product quality for both the management and the employees, TSI needs a quality manual or quality guideline, which can be used in the production line. By initiating a quality workshop, involving cross functional staff from different parts of the company, with the goal to create a foundation for a product quality framework. The work mainly focused on the product quality in the stitching teams. The most common errors and damages were gathered identified by the final quality controllers and experienced quality supervisors. Once the initial quality framework was created, the next step was to focus on the production in the stitching teams. The damages are categorized for the ten different stations that constitute the stitching of a complete shirt. For example, a common identified damage is misshaped collars. Damaged collars most likely occur in operation number 8. Hence, the specific damage was added to the customized guideline for operation number 8. The guideline thoroughly explains how to identify the damage and how to prevent it. The same process was executed for all identified recurrent damages, resulting in a specific guideline for each of the ten stitching stations. An example of the quality guidelines is available in 8.2 Appendix 2 – TSI Quality Guidelines, page 74.

To complement the written quality guidelines, each work station where provided with quality samples. Consider the same example operation as before, operation 8. Each collar stitching workstation was provided with a set of excellent quality samples of pre-made collars. Accordingly, the employee could visually compare the finished collar with the corresponding quality sample. The guidelines created were installed at each work station in Team C. The main idea is that each employee should check the quality guidelines when starting or finishing the work on a shirt. By doing this, the first quality check is actually performed by the machine operator himself, and the probability of quality damage diminishes. The idea with the concept is to move the quality assurance as early as possible in the production line. Even if damages occur they will be spotted earlier and will possibly avoid subsequent operations to be remade as well and thus minimize time waste caused by damages.

5.3.3.4 Product Innovation

The product innovation is considered to be out of scope in the particular case of TSI and this thesis. TSS is primarily responsible for product innovation and receives input from customers regarding product development (Ström, 2008). However, TSS and TSI need to have an ongoing communication regarding new product features. If TSS would like to include a new feature to a shirt, it is important to evaluate the impact on the production line together with the TSI production management. If this is not performed the risk of creating problems in the production increases.

5.3.3.5 Benchmarking

At the present time, TSI is not benchmarking the production towards other companies. Right now TSI probably needs to focus internally to maximize the effects of TQM. But it is recommended that TSI in the future study other successful firms in the garment industry or companies in different industries utilizing mass customization.

5.3.3.6 Employee Involvement

The importance of involving the employees should be emphasized. To ensure that the employees in Team C were involved in the change process several measures were taken. An initial meeting was executed where the importance of the quality aspects were introduced and explained. During the initial meeting, the management elucidated the correlation between a good product quality, a low rejection rate, and high team production output. The team had a trial period during a couple of days and the operators were encouraged to give feedback about the conducted changes to the management. It is also recommended that TSI continuously encourage ongoing suggestions and initiatives from the employees, which should aid in improving product quality. If the employees experience a feeling of importance and are a part of the forming of the quality change process, it is far more likely that they contribute with engagement leading to a superior quality process.

5.3.3.7 Reward and Recognition

TSI should improve the quality performance by giving employees recognition and rewards for good quality production. Another suggestion is to reward suggestions from employees that will improve the product quality. Rewards and recognition are powerful tools, strongly affecting the employee behavior. To acknowledge the importance of good quality at TSI, each month the team with the best quality is appointed. The team is provided with a monetary reward split between the team members. Another method used by the management is punishment of individuals causing product quality damages with salary reduction. To provide the employees with a positive image of quality, the authors advocate using rewards in contrast to punishment.

5.3.3.8 Education and Training

To achieve a successful TQM implementation, education and training of the employees are one of the most important factors. The aim for the education should be to make employees understand the importance of issues regarding quality and provide them with tools and techniques to solve the existing problems. The TSI quality guidelines could be used to make new employees understand how TSI define quality. TSI has presently monthly quality circles with the purpose to train and educate the employees about product quality. This is a good initiative and should be continuously performed. To emphasize the importance of product quality, the team leader of Team C and the responsible supervisor were invited to participate in a quality and TOC workshop.

5.3.3.9 Customer Focus

TSI does not have any direct contact with the end customers. Instead, the objective for TSI should be to view TSS as the customer. TSS should therefore be responsible to incorporate the end customer needs into the product and work as a middle-hand between TSI and the end customer. Hence, a developed communication system between the two sister subsidiaries is needed. TSI could benefit from a better understanding of what the end customer considers being good product quality. The objective to collect and compile this information should fall on TSS while TSI on the other hand needs to demand regularly updates. It is recommended that the TSI Quality Guidelines in the future in a larger extent is updated from data derived from customer feedback.

5.3.3.10 Product Quality

The nine constructors above all have the purpose of increasing the overall product quality. By using the constructors of Anupam & Swierczek a firm should be able to grasp the amplitude of the quality issues and start making efforts improving it. With the support of TOC, these efforts have been focused in the part of the production where they will have the highest contribution on increased throughput. TSI has followed the main part of the constructors with the objective to improve the product quality. The firm needs to continuously measure the rejection rate and set quality targets for the organization to achieve.

5.3.4 Results from the TQM Process at TSI

The implemented quality measurement routine makes it possible to compare the current rejection rate with the one measured earlier in February. The data is gathered from the rejection rate calculator and the results can be viewed in Table 7.

	Team A	Team B	Team C	Team D	Team E	Total
Feb Rejection Rate (%)	23,2 %	48,0 %	34,3 %	25,7 %	58,8 %	38,0 %
April Rejection Rate (%)	16,2 %	17,5 %	14,9 %	15,5 %	25,2 %	17,8 %
Improvement (%)	7,0 %	30,5 %	19,4%	10,2 %	33,6 %	20,2 %

Table 7: Final quality control, rejection rate, April 2008.

Notable when studying Table 7, Team C advanced from being the third best quality team to become the number one quality team during the studied period. Team C lowered their rejection rate from an average of 34.3 percent to an average of 14.9 percent which is a major improvement. The absolute difference amounts to a decrease of almost 20 percentage units. The impact on the rejection rate seems to prove that major improvements can be accomplished with the TQM methodology. However, the results shown in Table 7 clearly indicate that the other teams also improved remarkably. Taking a look at the total rejection rate of the five different teams in Table 7, it is concluded that the total improvement actually was almost the same as the improvement made by Team C. But the TQM program was mainly focused on Team C, so the question is; why has the quality rejection rate also improved in the other stitching teams?

The answer to the question could be that when utilizing the TQM methodology in team C and highlighting the importance of quality the remaining teams were also affected. The display of the measured rejection rate has probably made all teams realize the important of quality and initiated an effort to improve. Here follows a summary of the direct taken actions aimed at improving product quality for the stitching teams:

1. The involvement of the top management was initiated through two workshops with the goal to convince them about the importance of product quality.
2. The employees in team C were involved through two meeting with the goal to convince them about the importance of product quality.
3. The implementation of the quality measurement tool, TSI rejection rate calculator, conducted by the final quality control section.
4. Acknowledgment of a monthly stitching team contest, providing a monetary reward to the stitching team at TSI with the best rejection rate.
5. Continuously perform quality circles where the TSI employees can discuss the impact of quality to their work.
6. The completion of the TSI quality guidelines, which were customized to each work station within stitching team C.
7. The making of quality samples, which were customized for each work station within stitching team C.

Studying the seven concrete actions above, it becomes obvious that most of them will have an impact of all the stitching teams in the TSI production. There are three steps only relating to team C, namely number 2, 6, and 7. The rest of the measures were utilized for more or less all the stitching teams. Thus, by pinpointing product quality as the most crucial production measurement, the supervisors in TSI's production and the other team leaders have most likely accepted quality as a crucial success factor, and brought that knowledge within the other teams. The changes regarding quality have therefore not been isolated to the team C as the plan was initially; most of the changes have been utilized by the other stitching teams at the same time as well. In an environment like the TSI manufacturing plant, it is unlikely that the supervisors and the employees do not communicate on a day to day basis, spreading knowledge between different sections in the production line.

Another likely explanation to the major improvements showed by the figures is that when the first quality study was conducted, the quality rejection rate was unusually high. The rejection rate later altered itself to a lower level. This might be a part of the truth behind the vast improvements considering the rejection rate but cannot be confirmed since quality rejection rate data from other time periods are unavailable.

5.3.5 Exploiting Cutting Section – A Theoretical analysis

The second identified constraint in TSI’s production is the cutting section. The cutting section is a striking example of a classic constraint or bottleneck in a manufacturing firm’s production. Unlike the quality improvement conducted in the stitching teams, the authors have not implemented practical solutions in TSI’s manufacturing plant regarding the cutting section. The following chapter will therefore contain a theoretical analysis of how TSI could exploit and increase the capacity of the cutting section at TSI. The authors will finally provide TSI with recommendations for future improvement of the cutting section.

5.3.5.1 Avoid Capacity Drop with Employee Backups

TOC states that to maximize a systems throughput, the bottleneck sections must always be running. If not, capacity will be lost for the entire production, and this capacity cannot be regained. An evident capacity reduction occurs when for instance cutters are absent. The cutting section is considered a highly important task in the production line and the most experienced employees of TSI are working as shirt cutters. The physical space in the manufacturing plant is limited, and a cutting table will occupy a considerably large space. It is important that the cutting section is always running and do not idle. In the present situation, the cutters only work during day time. One method to solve this problem would be to change the cutters working scheme and also start to work night shifts. That would solve the space problem in the TSI factory, but a larger problem remains for TSI. Shirt cutters are a scarce resource, and consequently there are very few in the production or even in the market that master the task of shirt cutting.

If there are employees with cutting knowledge available within the TSI production line they should be moved to the cutting section. Applying the TOC philosophy, it is considered correct to move resources to bottleneck sections, from other non-bottleneck sections which per definition have overcapacity relative to the bottleneck. TSI could also use the method of job rotation. If the employees can learn more work tasks, it is also a larger possibility that they can be moved around in the factory to potential bottleneck sections. Hence the work force becomes a more dynamic resource for TSI. In the present situation the firm is utilizing an employee training program to achieve a multi skilled workforce. At this time, the program should be focused on educating more staff to become cutters.

5.3.5.2 Increase Capacity by Moving Fabric Quality Control

To ensure that the cutting section is working more efficiently, a solution would be to put the fabric quality control in front of the cutting section. Presently, if the fabric control section finds a specific damage on a piece of garment, the shirt cutters have to remake the specific part, thus wasting capacity. If the fabric quality control section were put in front of the cutting section in the production line, the cutters would only work with fabric that has been controlled, minimizing remakes of shirt pieces. The result would be increased capacity, which could be compared to the earlier line of action taken to lower the rejection rate in the stitching teams.

5.3.5.3 List of Recommendations to TSI

To summarize the above analysis, the authors provide a list of recommendations to TSI, aiming to strengthen the cutting section and increase the capacity:

- Move employees with knowledge of cutting from the production line to the cutting section.
- Keep developing the employee training program to provide employees with cutting skills.
- Start to utilize job rotation.
- Consider launching night shifts for the cutting section.
- Put the fabric quality control section in front of the cutting section.

5.4 Step 3 – Elevate the Constraint(s)

5.4.1 Chapter Overview

The third step in the TOC process is to elevate the previous identified constraint. This means that the firm could spend monetary resources to strengthen the bottleneck section. The purpose is to increase capacity as in step two, exploit the constraint. The difference is that in step 2 the firm does not use monetary resources to strengthen the bottleneck. This step has not been implemented in the TSI production and accordingly a short theoretical discussion will follow. Recommendations of how to possibly elevate the previous identified bottlenecks stitching teams and the cutting section will be given.

5.4.2 Elevating the Stitching Teams

The stitching teams will regain capacity from the measures taking in step 2. However, since TSI is an expanding firm it will most likely be necessary to further increase the capacity, thus elevating the stitching team section. Because of the current team setup, a straightforward solution resulting in increased capacity would be to extend the number of teams. This work has already begun, but the expansion faces some concerns.

- Skilled and experienced stitching operators is a scarce resource in the local staff market
- There is limited physical space in TSI's manufacturing plant

To educate a new employee to become a skilled operator working in a TSI stitching team takes a certain amount of time. TSI could however use the developed quality instructions to introduce the newly hired employees to TSI quality standards. Educating the employee to become a skilled stitching operator in thus achieved within a shorter time period.

The TSI factory has limited physical space, but it is possible to start working shifts. TSI has already initiated the use of shifts but the current factory space limits the capacity expansion, within the stitching teams, to maximum double capacity when utilizing night shifts. Therefore, TSI is planning to extend the factory, and has launched a construction program to add new floors to be able to extend the capacity further.

5.4.3 Elevating the Cutting Section

Aiming to elevate the cutting section, the same logic and arguments used in the above discussion regarding the stitching teams could in large extent be applied for cutting. The most obvious method to increase the capacity of the cutting section would be to simply recruit more cutters. One problem is that cutting, as mentioned before, is the most difficult task in TSI production. It should also be noted that the cutting craft is a greater challenge for TSI cutters since each shirt has different measures and require varying cuts. The challenge for TSI will be to find skilled and experienced cutters in the labor market. The problem with the limited space in the manufacturing plant has the exact same solution as discussed earlier. The first step for TSI is to start a night shift for the cutters, and the second step is to expand the physical space in the factory by expanding the current facilities.

5.4.3.1 Change from Manual to Semi-automatic

TSI could consider changing the cutting process, from manual to semi-automatic. The market could provide a cutting machine which could increase the efficiency of the shirt cutting. If this solution is feasible, at a reasonable cost, the capacity of the cutting section could be improved radically. TSI should scan the garment market for suitable solutions or initiate a benchmark study towards other firms in the same industry. This task is aggravated by the constant changing measurements. The machine will probably only be able to handle one shirt at a time. This suggestion requires further investigated by TSI before any conclusions can be drawn.

5.5 Step 4 – Subordinate Everything to the Constraint(s)

5.5.1 Chapter Overview

This main objective of this step in the TOC-process is to ensure that bottlenecks avoid idling. If not addressed properly throughput will suffer. This chapter strives to provide solutions and recommendations of how to control the flow of WIP to the bottlenecks and avoid starvation.

First follows a theoretical discussion about the impact of variance in TSI's production. Thereafter, the authors present an instrument that aims at solving some of the variance issues. The solution is labeled "the box system" and is a physical implementation. A software tool called "capacity balancing tool" is also developed and serves as a complement to the first solution. The software is used to minimize the effects of variance on a higher level and is applicable for the entire production. Finally a short summary of the overall findings is compiled.

5.5.2 Categorizing Variance

To facilitate the understanding of the problems described in this section variance will be decomposed in to two categories. Variance is an extensive concept and is influenced by several different factors. For instance there are several different sources causing production variance. The authors have divided variance into two different types. The categories are labeled: (1) *process time variance* and (2) *capacity variance*. These two measures are affected by different factors, but both add to the total production variance. The total production variance can be interpreted as process time variance + capacity variance. The major difference between the categories is that the second one, capacity variance, has obvious impact on capacity reduction while the first definition's impact is harder to grasp.

5.5.2.1 Process Time Variance

When identifying the constraint the capacity study included the standard deviation for each production operation, available in Table 3 on page 41. The process time variance is considered equal to the standard deviation calculated for each production step. Standard deviation measures on average how far the process time varies from the expected average process time. Accordingly, the process time variance defines the average deviation from the expected process time.

A short example is provided, demonstrating the meaning of process time variance. In this example, the process time is measured five times for three arbitrary production resources. Assume that the average time of completing one cycle for all resources is 25 minutes. An overview of the example is available in Table 8.

	Process Time #1	Process Time #2	Process Time #3	Process Time #4	Process Time #5	Mean Time	Process Time Variance
Resource 1	25	25	25	25	25	25	0
Resource 2	26	25	23	27	24	25	1,4
Resource 3	16	18	20	31	40	25	9,1

Table 8: Examples of process time variance.

Even if the three examples have the same mean time, 25 minutes, they have a considerably different process time variance. In the case of resource 1, the process times are all exactly the mean time, 25 minutes, thus the process variance is zero. Resource 2 has a relatively low process time variance of 1.4. In example number 3 the case is different. The five process times have a large variation and spans between 16 minutes and 40 minutes. This implies a higher process variance of 9.1.

5.5.2.2 Process Time Variance in TSI

There are several factors affecting the process time variance but they all have one characterization in common. They will all cause individual cycle to vary from each other. The level of variation will differ depending on several factors but one decisive parameter is the underlying source of the process time variation. Common sources of variations are human factors affecting the employee involved in the operation, for instance; motivation, experience, knowledge and others. Since the production is highly manual these factors will have an impact on the process time variance. Another source, more specific for TSI, is the utilization of the production strategy mass customization.

Cycles of certain production steps may vary considerably when considering process time. For example, imagine the operation responsible for manufacturing pockets in the TSI stitching teams. Sometimes a customer will order a shirt with no pockets, sometimes with one pocket, and sometimes with two specially designed pockets. Hence, the result will be that the process times vary strongly, just like in Table 8, example 3. In an ordinary mass production of shirts, usually all shirts have the exact same design, for instance only one pocket. This will imply that the process times are similar, like for resource 1 or 2 in Table 8. Isolated, process time variance has no effect on the average output but when present in a system consisting of a set of dependencies the variance might cause capacity reduction.

5.5.2.3 Capacity Variance

The capacity variance is the second factor affecting the total production variance. It has a direct effect on capacity. In most cases the capacity variance will soon have a noticeable effect on the expected output from the affected production unit. To understand the capacity variance an example will follow. A production line with a production resource with the output capacity of 45 units/h, consisting of 3 machines, has a sudden temporary machine break down. The machine is out for 3 hours and lowers the capacity of the production section to 30 units/h. This results in an output drop of 35 units. This is a simple example with obvious impact on output caused by capacity variance.

5.5.2.4 Capacity Variance in TSI

Considering the case of TSI, capacity variance is most often a result of absent employees. For example, an employee at a specific section can process an average of one shirt every 30 minutes. This specific section has a total amount of ten employees. This will imply that the section can process a total number of 300 shirts during an eight hour working day. Naturally, sometimes employees will be absent from work due to different reasons. If one employee is missing it is easy to understand that the total number of processed shirts will decrease from 300 to 270 shirts. This is an example of capacity variance in the TSI production line. Other examples of sources to TSI capacity variance are power failure and machine breakdowns. The most common however is employee absence.

5.5.3 Moving Bottlenecks in TSI's production line

A phenomenon observed during the early part of the TOC-process was large levels of moving WIP. The continuously shifting stock of high inventory points towards mobile bottlenecks. The high level of WIP stock is likely caused by variance which is also confirmed by other researches (Leitch, 2001; Banker et al, 1998). A likely source is the capacity variance caused by absent employees. The TSI factory is subjected to approximately 10 percent absentees each day (Shyamalie, 2008). The impact of the capacity variance is that different parts of the sections in the production line randomly get affected by high variance. The process time variance however is most likely to stay more or less the same for a certain production unit. This is true at least if we consider the process time variance caused by mass customization. Imagine two separate production sections, one where the required time varies depending on the product attributes and another section whose work will remain unchanged independent of product attribute. Naturally, the first section will be subjected to higher process time variance. Since it is impossible to determine where the capacity variance will strike, this type of variance has a higher probability of causing inventory to move.

Consider the example of a section with three employees. With one employee absent the section will lose 33 percent of the total capacity due during this day. This must be considered as a major impact and occurs because the section has a low number of employees and therefore is sensitive against absentees. If an employee is absent in a sensitive section with a low amount of staff, the risk is that this section will become a temporary bottleneck. It can also be concluded that sections with low capacity run the risk of becoming potential bottlenecks in the TSI production.

Consequently, the high variance should tend to create moving bottlenecks in TSI's production. It is harder to handle constant moving bottlenecks for the TSI management. This implies that the management is subjected to a daily struggle of identifying and exploiting moving bottlenecks, which becomes a time consuming task.

The TSI management could use a tool to deal with the production variance, with the purpose of aiding the daily balancing of the production required because of variance. Two management tools have been developed to meet this purpose: (1) *the box system*, and (2) *the balancing tool*. The box system is a practical system with boxes, designed to neutralize the effects of process variance while the capacity balancing tool is aiming to reduce the effects of the capacity variance.

5.5.4 The Box System

To verify the box system, the authors decided to perform an implementation in an isolated part of TSI's production line. It was practically suitable to test the system in the same stitching team as earlier with the quality improvement program, namely stitching Team C.

The box system provides the responsible managers with a practical and tangible solution to deal with moving bottlenecks and process time variance. As Figure 10 page 36 shows, Team C consists of a number of dependent operations. All of these operations range from a minimum of one operator, to maximum three stitching operators. The numbers of employees have been set by the TSI management, aiming to balance the stitching teams. When using the expression balance, the intention is to have a production line with similar capacity. Before changes were made to the team each of the operators in the team had a box at their working station. This box contains shirts waiting to be processed and has an approximated maximum capacity of 30 shirts.

The main problem is that the process time variance is causing some team stations a lower capacity. If this is the case, these stations will produce fewer shirts than the station located before and after. The main consequence of this is that the current station, which is subjected to a temporary high process variance, will receive an increasing number of shirts in the belonging box. If this continues long enough, the next station will begin to idle because it is not receiving shirts fast enough. In other words, if the following station works relatively fast during some time, this implies that the team will lose production capacity due to stations idling and cannot perform their work.

The operation number with the lowest capacity becomes a temporary bottleneck in the stitching team. Accordingly, the team leader has to strengthen the bottleneck. The faster this is done the better for the team output of shirts, following the above reasoning. Thus, the number of shirts in the boxes is working as a measuring device, which indicates if a station in the team has capacity problems.

The goal was to increase the visibility of the number of the shirts in the boxes, thus creating a signaling system to trigger action from the responsible team leader. Inspiration was taken from the famous Japanese Kanban system in Toyota (Ohno, 1988), and the forming of the box system started. The implementation of the box system required concrete action and so every operator's box within the team was switched to specially designed boxes. The new boxes are designed to contain a maximum of ten shirts per team operation.

If the specific operation has more than one operator they need to share the new box. Accordingly, the maximum shirts waiting to be processed in a station should be ten shirts. The team consists of totally eight operations which mean that the maximum amounts of WIP in the team are 80 shirts. If the limit of ten shirts is exceeded the employees are instructed to immediately inform the team leader, so that suitable action can be taken. A proper response from the team leader would be to address team employees from operations lacking shirts to support the section with a large stock of WIP. Once the temporary constraint has fewer shirts and the flow is secured, the team leader should switch back to the original team setup.

The response from the test team was good, and the use of the box system should theoretically lead to a higher production output for the stitching team over time. No measurement is available to prove this fact, but using the system should reduce the effects of the process time variance. The team leader gains the possibility to react rapidly to upcoming temporary bottlenecks in the team and move capacity to prevent reduced capacity utilization.

The same logic used when implementing the box system into a stitching team could be used in the entire production. A stitching team is in fact a miniature of the TSI production line. One challenge for TSI is to decide how many shirts waiting to be processed are most suitable for each production section. Hence, the authors recommend the TSI management in the future to implement the box system in the entire production line.

5.5.5 The Balancing Tool

The second tool created is named the balancing tool, and is designed to neutralize the effects of the capacity variance in TSI's production line. The tool is a program created in Microsoft Excel, which could be utilized by the TSI production supervisors, see Figure 13. The stitching teams have a similar but separate tool and are not included in the illustration below.

Sections	Process Time (min)	Setup Time (min)	Hourly Production (nbr)	Staff (nbr)	Theoretical Daily Production (nbr)
1.Shirt cutting	26,12	1,25	17,5	11	193
2. Collar cutting	4,58	0,50	94,6	3	284
3. Fabric checking	6,92	1,00	60,6	4	242
4. Ironing 1	7,55	0,50	59,6	5	298
5. Fusion 1	2,69	0,50	150,3	1	150
6. Ironing 2 + Fusion	2,66	0,50	151,9	1	152
7. Cutting of placket	2,34	0,50	169,0	1	169
8. Cuff drawing	2,28	0,50	172,9	2	346
9. Button hole	4,35	2,00	75,6	2	151
10. Extra button	2,87	0,50	142,6	2	285
11. Button hole clea	5,55	0,50	79,3	3	238
12. Button mark	3,10	0,50	133,2	2	266
13. Button attatch	3,05	2,00	95,0	3	238
14. Final Quality Che	13,72	0,50	33,8	8	270
15. Packing	11,86	0,50	38,8	8	311
16. Scan and send	1,35	0,25	300,0	2	600

Bottleneck limits:		TDP = Theoretical Daily Production
Danger		TDP < 160
Be alert		160 < TDP < 220
Safe	220	TDP > 220

Figure 13: The balancing tool, developed in Microsoft Excel.

TSI has a current problem with attendance of the working staff. This is causing random sections in the production to lose severe amount of capacity, and could result in unexpected bottlenecks. The balancing tool should be used daily, to prevent the effects of absent employees in the production. Each morning the production supervisors of TSI must check the attendance among the TSI staff. The number of employees should be input into the balancing tool in the column named Staff. When this is done, the program calculates the estimated capacity of each section. It should be emphasized that the program excludes the process time variance discussed earlier.

In Figure 13 the program is manually configured to a production throughput of at least 150 shirts per day. This limit is later possible to alter for the supervisors. The program also has traffic light indicator, which displays the expected status of the section, see Figure 13.

- A green light indicates that the section has the status *Safe*, thus the section should be able to produce more than 150 shirts. The limit for a green light is 220 shirts/day, and the section will probably be able to adjust for process time variance, still producing more than 150, which is the minimum amount of shirts per day.

- A yellow light indicates that the section has the status *Be Alert.* The limit for the section is between 160 and 220. The section should be able to produce 150 shirts, but the production supervisors need to stay alert, and might have to exploit the section, if it is affected by a high amount of process time variance.

- A red light indicates that the section has the status *Danger*. The limit is equal to or below a daily capacity if 160 shirts. If a section has a red light immediate management actions must be taken. The section needs more capacity, and the correct action would be to move staff from another section with a green light to red light section, which poses as a potential constraint. If the process variance has even a small impact on red light section, it might not be able to produce 150 shirts per day, thus becomes a bottleneck in the TSI production system.

5.5.6 Additional Suggestion – Multi Skilled Team

A convenient complement to the Balancing Tool is to put together a team of multi skilled employees. This team should consist of employees with various skill and experience from the different sections in the TSI production line, and should function as a back up when employees are absent. TSI need to assemble the team and continuously accomplish job rotation for the team members. By using a multi skilled team, TSI could reduce the impact of capacity variance caused by absentees in the production. Consequently, less job rotation would be required and the workers in the line won't have to worry about moving to a different section.

5.6 Step 5 – Repeat the Process

5.6.1 Chapter Overview

The fifth and final step in the TOC process is to repeat the process. This is a fundamental principle utilizing TOC, and the work to identify and strengthen constraint must be performed continuously.

5.6.2 TOC – A Continuous Improvement Process

When using the TOC as an improvement management tool, it is important to understand that the use of TOC is an improvement process that needs to be repeated over and over again.

A firm must not be satisfied with utilizing the TOC process only once, and this is an essential factor to consider for the case study company TSI. The company must continue to scan the production for bottlenecks. TSI is an expanding company and is planning to add additional production resources continuously in the near future. When doing this the system will be affected. Therefore, it is important to understand that the TOC process needs to be continuously repeated and fine tuned over each cycle to maximize the available capacity in the TSI production line. During the conducted study the authors allocated time to educate the management about the process and this study will also serve as support when carrying on the TOC-process.

Some practical recommendations for TSI are to continue working with the quality improvement system to further improve the product quality. The authors also recommend the firm to continuously use and develop the box system and the balancing tool in the entire production line. Finally, the knowledge and the understanding of the different systems and management tools need to be communicated to all of the employees of TSI, both management and workers. If TSI can manage to continuously repeat the TOC process, the firm has the possibility to obtain the goals of increased throughput and improved productivity.

5.7 Summary of the TOC Process

Step 1 – Identify the Constraint(s)

To identify the constraints in TSI's production five methods were used:

1. Capacity study
2. WIP study
3. Production data study
4. Employee interviews
5. Product quality study

Using the above methods, two main constraints were identified:

- The Stitching Teams, low capacity mainly due to poor product quality
- The Cutting Section, low capacity mainly due to a lack of available cutters

Step 2 – Exploit the Constraint(s)

To exploit the identified constraints, the following actions were taken:

- **The Stitching Teams**
  To improve the product quality in stitching teams, the TSI quality improvement system were developed utilizing the framework of TQM. This improvement system was implemented in a TSI stitching team, and the result was a major improvement of product quality in the test team. The rejection rate in the selected test team was reduced from 34.3 % to 14.9 %, which implies an absolute improvement of almost 20 percentage units.

- **The Cutting Section**
  A set of recommendations were developed to TSI's management. The main recommendations are that the management needs to move employees with cutting experience in TSI's production from non-bottleneck sections to the cutting section. Other possibilities are to utilize shift working and altering the production setup line to maximize the capacity of the cutting section.

Step 3 – Elevate the Constraint(s)

To elevate the two identified constraints a set of recommendations were given:

- **The Stitching Teams**
  The most important recommendation is to allocate more teams to increase the capacity. TSI needs to expand the physical space in the production facility and hire and train new employees to become skilled TSI stitching operators.

- **The Cutting Section**
  The obvious solution to elevate the cutting section is to hire more cutters. Again, TSI needs to build a larger production factory to increase the work space and hire and train new employees to become skilled TSI cutters.

Step 4 – Subordinate Everything to the Constraint(s)

To subordinate the production line to the constraints, the importance of dealing with the variance in the TSI production is highlighted. It was concluded that TSI have a high level of variance, process time variance and capacity variance, in the production. The effects of the variance are causing temporary moving bottlenecks to occur in TSI's production line. To manage the negative effects of variance, two tools were developed:

- **The Box System**
  The box system is a hands-on variant of a Kanban system, which helps the management to reduce the negative impact of process time variance in the TSI production.

- **The Balancing Tool**
  The balancing tool will help management to reduce the negative impact of capacity variance in the TSI production line. To complement the balancing tool, TSI could assemble and train a multi skilled team, which should contain a number of employees who can work in every section in the production line.

Step 5 – Repeat the Process

The TOC process, summarized above, needs to be repeated continuously. When TSI for example is changing the production setup or is expanding, the company most likely will need to revise the TOC process and fine tune the quality improvement system, the box system and the balancing tool.

6 Mass Customization Production Concerns

6.1 Chapter Overview

This chapter aims at answering the stated purpose of this thesis. Several production management concerns, and there linkage with mass customization, will be brought forward to discussion. An extended analysis of the observations made at the case study company will launch this chapter, followed by a discussion concerning quality. Finally, a verification of both the suggested proposition and the constructed framework are presented.

6.2 Solving Tailor Stores Concern – Decreasing the Lead Time

TSI's major concern refers to their extended lead times. The problem discussion in Chapter 4 specifies that TSI has a queue prior to the production holding 1500 shirts, and the production line itself has 1500 shirts in process, which amounts to a total of 3000 unfinished shirts. Even though all of these orders are not physically distributed in the production the total WIP is considered to be 3000 shirts. These orders already amount as throughput since they have generated a sale. This is a fundamental difference compared to a classic, non-order-based, production where production is partly based on predictions. In *The Goal,* a decrease of lead time is achieved by minimizing WIP by focusing production on parts that with high certainty will amount as throughput. The possibility for Tailor Store to use the same method to govern WIP is limited, because the company adopts a high-level mass customization strategy. Another method used in *the Goal*, is to supply identified bottleneck sections with a large safety stock, to prevent bottleneck idling. This method is however also feasible for Tailor Store. No parts of the shirt can be produced in advance, since the customer is required to participate in the design phase. Guessing what product attributes a customer would prefer is simply not realistic. The WIP is therefore strictly tied to the amount of received orders. Assuming that Tailor Store wants to avoid limiting sales, it becomes impossible for TSI to reduce WIP, since existing WIP already account as throughput and requires production.

Shifting WIP from the production will only result in a queue prior to the production and will not decrease the total lead time. For instance, decreasing the WIP available in the factory from today's 1500 to 1000 will lower the manufacturing lead time. But the removed WIP will not disappear; instead it will be relocated to the queue in front of the production. The total queue therefore remains unchanged and will not reduce the lead time. Hence, it is not adequate to remove excessive WIP from the production, since the adopted business model does not allow non throughput WIP to exist.

Little's law states that the manufacturing lead time is proportional to WIP and inversely proportional to throughput. Since the flow of WIP always remains equal to the amount of sold shirts, the only remaining parameter for TSI to fully control is the throughput. A discussion regarding how to manage and maintain maximum throughput in this particular situation will now follow. The following three parameters are considered decisive when administrating throughput:

- Capacity
- Variance
- WIP

The capacity is regarded as the crucial parameter since it defines the upper limit of the throughput. WIP and variance may on the other hand lower the throughput if not governed and could therefore be regarded as a threat to maximum capacity utilization. As pointed out earlier in this thesis, a certain level of capacity allocated to a certain production step does not guarantee the expected output. This is due to a high level of process time variance and a lack of WIP. Since throughput remains as the only available candidate for decreasing lead time, it requires additional attention. To achieve full control of throughput the underlying parameters are decisive.

As declared earlier, WIP only constitutes already sold shirts. TSI have, during periods, had a daily order input of 200 shirts and if throughput is properly synchronized with the market demand, the WIP should account to approximately the same level as the daily order input. But this is far from the present truth at TSI. With a WIP stock of 3000, the straightforward conclusion is that the throughput is too low. Further, the TOC process at TSI indicates that the available capacity is insufficient, since today's throughput level of 150 is far away from the desired 200. There are only two possibilities available explaining the insufficient throughput. The first possibility is the one recently stated that the capacity of one or more production steps is insufficient which creates bottlenecks in the production, limiting the throughput. The second alternative is that the production has sufficient available capacity but variance combined with inadequate WIP limits the production from reaching the potential capacity and thus lowering throughput. To avoid these two scenarios, and successfully attain a shorter lead time TSI needs to:

- Acquire sufficient capacity and divide it strategically.
- Manage both capacity variance and process time variance.
- Minimize the WIP required to neutralize the effect of variance.

These three steps will now individually be further discussed.

6.2.1 Acquire Sufficient Capacity and Divide it Strategically

The authors argue that there are two basic dimensions to consider when governing capacity. Firstly, to reach the market demand, sufficient production capacity is required since capacity determines the theoretical maximum limit for a system's throughput. Secondly, it is crucial to consider the allocation of the available capacity in the production line. As explained earlier, TOC states that the throughput of the system is bound to the system link with the lowest capacity. Therefore, it is relevant to plan the distribution of capacity and later monitor it to ensure maximum throughput. Monitoring is necessary because of capacity variance, which will be discussed further in the next section.

The case study at TSI revealed that the company lacked both capacity and a structured method for allocating capacity to the production units in need of additional capacity. The conducted TOC-process improved both issues. The production sections with the lowest capacity were identified and strengthened. In addition, the capacity study provided a mapping of the current allocation of the available capacity. Thus, the study serves as a foundation for future decisions about capacity acquirement. The authors recommend TSI to establish a routine of continuously revising the currently available capacity in a capacity map, similar to the capacity study developed during the TOC-process, see Table 3 page 41. In addition, this information will provide the firm with an awareness of the location of potential bottlenecks, when variance is not taken in to consideration.

The curious reader may ask how the capacity should be divided most favorably. If the production was liberated from variance the capacity should be equally divided amongst the production units. But since variance is present in all productions, a perfectly balanced system is not favorable. Goldratt (1984) claims that production resources located at the end of the production line should have more capacity available than the ones located at the beginning. Indications of this assumption were observed during this study. In the TOC-process at TSI, the cutting section was concluded to be a constraining resource and it is located at the start of the production. Apart from the stitching teams, all subsequent sections have a higher capacity than cutting. Historical production data of TSI, available in 8.3 Appendix 3 – Production Data, shows that the output from the last production section is similar to the cutting sections output and this indicates that the assumption is correct.

There is a second way of interpreting Goldratt's assumption. The market demand serves as a direct input to the first operation in the production, which later travels through the production as WIP. If the bottleneck is located at the end of the line and the previous resources have a higher capacity, problems might still occur. If the preceding sections are subjected to variance that causes a prior operation to output fewer products than the capacity of the bottleneck, a decrease in throughput might occur. But if the bottleneck is placed as close as possible to the market input, this will guarantee the bottleneck access to the WIP requested by the market.

6.2.2 Manage Both Capacity and Process Time Variance

Earlier in this thesis, variance was divided into two separate types. This section aims at providing a deeper understanding for the notions along with some guidelines that describe how to manage these types of variances.

TOC emphasizes that bottlenecks should never idle. A system subjected to high variance will face a greater challenge in achieving this, compared to a system with low variance. Controlling the flow through the system is obstructed by the variance. The case study reveals that the type of variance that has the highest level of influence on TSI's system is the capacity variance. Previous mentioned examples of capacity variance are employee absentees and machine breakdowns. The variance has a high potential of weakening a resource and substantially decrease the capacity during prolonged periods. Depending on the capacity variance's underlying causes, different measures to resolve the problems are required. The purpose of the developed balancing tool is to manage absentees within TSI's production. This is a direct response to one source of capacity variance and makes it possible for the production management to balance the capacity in an uncomplicated way. An additional advantage provided by the balancing tool is that the tool highlights the location of the current theoretical bottleneck. If capacity decreases in a high extent, it might cause the bottleneck to move to the section affected by the capacity drop. The frequently occurring mobile bottleneck phenomenon appears because the production, in a high extent, is based on man power and not machines. The balancing tool supplies the management with the knowledge of where in the production line problems should be avoided permanently. For instance, a disturbance at a relocated bottleneck might affect the complete production throughput, while disturbances at non constraint resource will not be as urgent. Without the balancing tool the management might not be aware of that the troubled resource already has been subjected to capacity variance. Since the production resource normally is not considered as a bottleneck the problems might not be addressed immediately.

The study at TSI revealed an unexpected permanent type of capacity variance that was reducing capacity for a large part of the production. Product quality issues caused work to be remade which resulted in a capacity loss at the stitching teams and the final quality control section. Thus, poor product quality could be considered as capacity variance. The quality concerns have a substantial impact on the capacity and therefore qualify as capacity variance. From a production perspective, it becomes important to monitor quality closely; similar to how other capacity variances need to be observed.

The second category of variance was named process time variance. The process time variance depends on various different factors and differs between the production operations. The process time will over time average out, but during shorter periods large differences in process time might occur and cause the system lowered throughput. This concern was solved at TSI by introducing the box system. The boxes clearly display the available WIP and function as a warning system. When WIP is close to zero a section risks idling which can be particularly unfortunate if the section is a bottleneck. The box system serves as an early indicator and allows the production management to act upon starving resources. Since the starvation temporarily can be caused by process time variance the box system reduces this harmful effect.

It should be noted that in the case of TSI, the capacity variance constitutes a larger part of the capacity loss and thus becomes more relevant to manage. But focusing purely on capacity variance may cause valuable throughput to be lost, because process time variance is overlooked. Organizations need to consider what amount of resources to spend when managing process time. The gain has to exceed the cost and manually adjusting process time variance might require large efforts. The box system developed for TSI advises the workers that the next station might idle and they simply need to inform a supervisor about the potential problem. With the capacity balancing tool available, the supervisor can further decide if actions are necessary or not.

6.2.3 Minimize the WIP Required to Neutralize the Effect of Variance

The level of WIP has a direct influence on lead time. Eliminating WIP, when possible, thus becomes desirable in most cases. But WIP should not solely be regarded as negative. If a high level of WIP is available it guarantees the different production units access to work. WIP could be viewed as a form of insurance that prevents production sections from idling. TOC provides a simple guideline when dealing with WIP; primarily allocate WIP to the bottlenecks. As easy as this may sound there are several practical concerns associated. In the case of TSI, building WIP independent of received orders is virtually impossible because of the high level of customer involvement in the product design phase. Thus, WIP only becomes available when customer orders are received. Since WIP cannot be produced ahead of a customer order it instead becomes relevant to control the flow through the production. To explain how this can be accomplished a simple example will be studied.

In this example two production operations are illustrated, 1 and 2. Also, two teams are present (A & B), each containing both operations. Each team has two workers. One worker is more efficient and has a higher capacity. No WIP is assumed to be available in the example. The example is split into two scenarios, in the first the teams are separately located and in the second they are joined.

Resource	Capacity
A1	5 units/h
A2	3 units/h
B1	3 units/h
B2	5 units/h

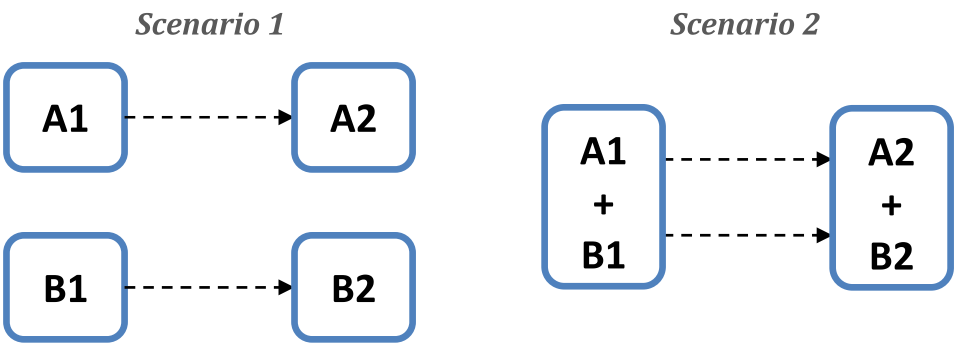

Figure 14: The left side of the figure represents separately located teams and the right shows a merger between the teams.

In scenario 1, left side of Figure 14, the teams are separately located and have individual stocks for WIP. After one hour has passed, both teams will output 3 units each which amount to a total of 6 units. In scenario 2 however the stock of WIP is shared. This output from the second scenario is 8 units, which are two units more than in scenario 1. This simple example shows that combining single workers together in larger units with shared WIP in fact could increase the output.

The example demonstrates an important point to consider when designing the physical production layout. One extensive production line is favorable to a set of small lines because the flow of WIP will run more smoothly. What a larger line actually does is to reduce the effect of the process time variance.

Assume that the different output of the resources illustrated in the example above was actually caused by process time variance. Further, assume that the expected capacity for all resources (A1, A2, B1 and B2) actually is 5 units/h. Thus, during the illustrated hour in the above example, A2 and B1 temporary dropped from 5 units/h to 3 units/h. The capacity drop in scenario 1 has caused an output of 6 units compared to the expected 10. Scenario 2, also subjected to the same capacity drop, has an output of 8 units compared to the same expected output of 10 as in scenario 1. Consequently, the same process time variance caused the two scenarios to loose different amounts of output. Scenario 1 will lose 4 units while scenario 2 will only lose 2 units. This example shows that a single line with a shared stock of WIP is favorable to a set of small lines. TSI is concluded to have a high process time variance and thus need to consider scenario 2 as a potential future concern.

Today TSI has a large stock of WIP in the production. Once again consider the example above. Scenario 1 would most likely not yield a 4 unit decrease since TSI has such a large amount of WIP available in all sections. Resource B2 whom is waiting for B1 will probably have WIP available, thus will not idle and lose capacity. However, TSI should not rely on the high level of WIP in the future, because when the capacity and throughput is increased the WIP will eventually be reduced. The high level of WIP in the production is currently present because TSI suffers from inadequate capacity. When the level of WIP is decreased it becomes vital for TSI to possess a production system that will only require a low level of WIP to operate smoothly. Organizing the production to allow shared WIP stock is one solution. The firm should therefore consider revising the production setup to a pure line system, since the example clearly shows that this is reducing the effects of process time variance.

While the responsibility to optimize handling of the available WIP lies at TSI, the companies TSI and TSS share the goal of creating balanced levels of WIP. Since WIP is dependent of the customer orders, TSS has to be involved in the task of creating an optimal level of WIP, provided that the capacity corresponds to the order flow. The level should suffice to allow a certain production resource to maintain the desired level of capacity. A WIP level higher than that is unnecessary and will only cause additional manufacturing lead time. A reasonable estimation would be that one day’s production of shirts is enough to guarantee a sufficient WIP in the production line. For example, if TSI has a daily throughput of 300 shirts, a sufficient number of orders waiting to enter the production are 300. It should be noted that one day’s production delay is merely an estimated value and further investigations are needed to establish the optimal level of WIP required in the case of TSI.

6.3 Quality, Production and Mass Customization

The case study at TSI revealed that the company had serious internal product quality issues. This section will examine the correlation between the product quality concerns and mass customization.

Consider a production line operating according to a mass production concept. The production line manufactures large batches of shirts, say 10 000 shirts per batch. When launching a new batch, the production operators will most likely make some errors. This is due to that each new batch will imply changes in the existing production line. But after producing a certain number of shirts, the production line will, in most cases, adapt to the new product which resonably would results in fewer errors and product damages. Initial, the product quality will, to a certain degree, proportionally improve together with the rising number of produced shirts. When sufficient experience is gained the level of damages will plane out to a stable level.

Now consider a similar production using the mass customization concept. The form of mass customization adapted by Tailor Store implies that every manufactured product is customer unique and largely variable when considering product attributes. As previously has been mentioned, this requires a batch-size of one product only. In TSI's production the batch-size is resulting in shifting work requirements for several operations. The learning effect in the production line, discussed in the mass production example, will thus not be as easy to obtain. This will imply that the production line using mass customization will reasonably have a higher amount of quality errors and damages, resulting in an overall lower production quality. This suggest that when using a mass customization strategy, it becomes further important to monitor quality, striving to enhance good product quality in the production.

This reasoning would partly explain why TSI had a high rejection rate of shirts in the production. This is however not likely to be the only reason. Other factors affecting product quality at TSI could be that the organization is very young and thus the production is still learning. The production have conducted changes to the setup several times during a short period of time. TSI also have a lot of newly hired employees, which can be expected to cause more erros than experienced employees. Further, the fact that TSI did not use a general product quality manual in the production line might also be an explanation to the high amount of shirts rejected. The management, the quality controls, and the employees did not mutually define good product quality in the same way. The impact of these other factors need further attention, but it has not been the main focus in this thesis. Therefore, the authors recommend the subject of quality concerns related to mass customization for further research.

6.4 Verifying the Proposition

In the introduction chapter the authors' presented a proposition. Supported by the gathered experience and knowledge from the case study and the conducted analysis, a discussion will now follow, intending to verify the given proposition.

> **Proposition:** Mass customization strategies results in increased production variance which raises the probability of reduced production output.

Mass customization is a business strategy that implies that the customers have a possibility to make multiple choices regarding the product features. This fact will inevitably affect the production system, and furthermore influence production variance. During the case study, the production variance was divided into two categories, process time variance and capacity variance. The authors imply that the studied form of mass customization strategy is likely to have an impact on both types of variances.

The case study showed that production sections that are subjected to a large extent of varying product features have higher process time variance compared to sections unaffected by variable product attributes. This implies that some TSI productions steps have an unpredictable complexity factor that depends on customers' selection of product attributes. An example from TSI's production is station 1 in the stitching teams. This station has many multiple choices and also one of the highest measured process time variances, which thus can be directly derived to an impact from mass customization.

The case study also revealed that TSI had product quality concerns. A high rejection rate of shirts caused products to be remade which resulted in lost capacity in the stitching teams. Quality concerns are considered to be part of the capacity variance. The analysis indicates that it is a challenge to achieve a high quality level utilizing mass customization. Consequently, the strategy mass customization has an increasing impact on the capacity variance.

Accordingly, production lines utilizing mass customization tend to have a higher process time variance, and at the same time tend to have a higher capacity variance, which added together implies a higher overall production variance.

As stated by TOC, and confirmed by this study, a production resource with high variance, located in a dependant production system, will affect the production line negatively. For instance, high variance increases the risk of causing the following dependant sections to idle. If the subsequent section is a bottleneck the entire production system is caused to lose throughput.

Using the above reasoning, the authors have showed that TSI is subjected to a higher production variance derived from the use of a mass customization strategy. The connection between a high variance and a limited system throughput has been emphasized, thus the authors argue that the proposition is verified. However, the authors would like to call attention to that this thesis only concerns one case study object, with one certain level of mass customization. Therefore, to achieve additional verification of the stated proposition, the authors challenge other scholars and academics to perform further research.

6.5 Evaluating the Theoretical Framework

By using the two established management theories TOC and TQM side by side, this thesis attempts to identify production management concerns raised by utilizing a mass customization strategy. The authors have not been able to locate any previous research combining the three subjects and strive to initiate the filling of this gap. The results of this case study undoubtedly point toward a high level of applicability of the combined theories.

The analysis in this chapter verifies an existing correlation between increased production variance and mass customization. This verification was achieved by combining the procedure of a hands-on implementation together with a theoretical analysis, both involving TOC and TQM. Throughout the thesis focus has been placed on TOC, since the theory is considered closely related to production concerns. TOC takes stochastic variation into consideration and thus proved to be a suitable theory for verifying the suggested proposition. Further, TOC provided a foundation for understanding the production related concerns. When expanding TOC to include basic queuing theory, through Little's law, additional understandings were gained. These findings were used by the authors to resolve Tailor Stores lead time concern. The effect of mass customizations on the ability to control WIP was also elucidated. A word of caution would like to be advised when employing TOC. Even though the theory is fundamental it might overlook practical concerns. Expanding the research to include TQM armed the framework with an additional perspective. TOC emphasizes variance while TQM provided practical guidelines regarding product quality. Combined, the two theories helped the authors to understand that quality concerns and product attribute variability are two main sources of variance in a production environment utilizing mass customization.

TOC and TQM have supported the authors in fulfilling the purpose of this thesis. Additionally, the theories have greatly contributed to the practical implementation improvements conducted in the studied case company TSI. Results from this thesis give the authors reasons to recommend further studies with a similar framework as a basis. Once again, consider the illustration of the theoretical framework, see Figure 15. The picture is not a finalized model, but only works as an illustrative example. The success in the production line of a manufacturing firm could be compared to how fast the mass customization cogwheel in the picture is running. Indeed, TOC and TQM contributes to make the mass customization cogwheel operate fast, smooth and safely. The authors argue that TOC and TQM provide insights, enabling companies to utilize mass customization adequately. Operating the center cogwheel will become more difficult without the supporting cogwheels illustrated by TOC and TQM. However, the authors do not exclude that additional theories could improve the mass customization cogwheel to operate even better, but leave this tempting challenge open for future research.

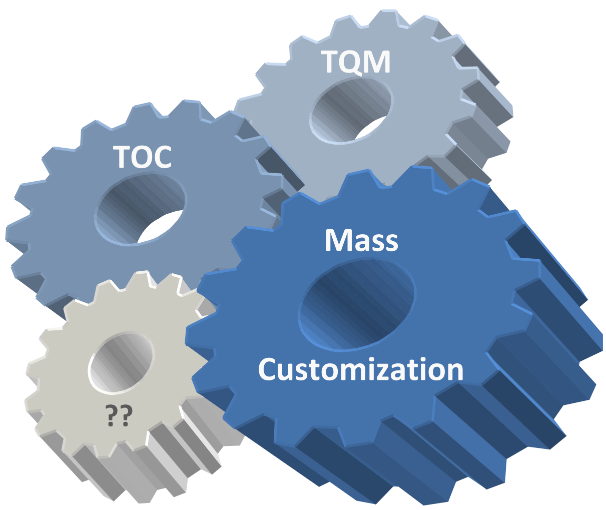

Figure 15: An illustration of the possible development of the theoretical framework.

7 Conclusions

This chapter summarizes the main conclusions drawn in this thesis.

The result from the case study indicates that the studied form of mass customization strategy will:

- Result in increased production variance. Increased variance causes a higher probability of limiting capacity which might cause unexpected bottlenecks to arise. The increased variance is constituted by two categories of variance:
    - The process time variance, which is increased due to high product variability derived from multiple customer choices.
    - The capacity variance, which is increased due to a batch-size-of-one which implies a higher risk of product quality issues.
- Imply that WIP is strictly tied to the market demand and cannot isolated be controlled by the production management. This is due to the high involvement of the customer in the design phase.

The case study further shows that:

- TOC is a suitable management tool when utilizing mass customization, because it highlights the concern of variance and bottlenecks.
- TQM is a suitable roadmap for a mass customizing firm to improve product quality concerns using practical methods.

7.1 Recommendations for Further Research

When realizing this thesis, the authors identified subjects in need of further attention. Considering the limited time frame and a narrow focus, the authors would like to encourage other academics and scholars to continue the research initiated by this case study. The following questions were raised throughout the work process of writing this thesis:

- Can the findings and conclusions in this thesis be verified by studying other case study objects using different levels of the production strategy mass customization?
- What is the quantified cost of variance in a mass customization environment? Is it possible to quantify the cost of variance by using a financial view?
- In this thesis TQM was utilized to improve the product quality. Under similar circumstances, is it possible to gain equivalent results using other quality tools, for example six sigma or lean management?
- How should the production management deal with quality issues in an automatic production line utilizing mass customization? Will an automatic production line show the same characteristics regarding product quality as manual production? To what extent are the manual production setup and the human factor affecting the product quality?
- Extend the suggested framework presented in this thesis by testing additional theories together with the presented theories in this thesis. A suggestion is to investigate how the theoretical framework should be completed when including suppliers in the problem scope.

8 Appendix

8.1 Appendix 1: TSI Rejection Rate Calculator

8.1.1 Quality Sheet – Data input

Section	Quality checker													
	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Team A - Checked	1	3	1	6	5	1	4	0	1	5	3			30
Team A - Failed	1	0	0	2	2	0	1	0	0	1	1			8
Team A - Re-check fail	0	0	0	0	0	0	0	0	0	0	0			0
Team B - Checked	4	2	1	3	1	2	1	3	2	3	2			24
Team B - Failed	1	0	0	0	0	0	0	2	0	0	0			3
Team B - Re-check fail	0	0	0	0	0	0	0	0	0	0	0			0
Team C - Checked	2	6	10	7	6	4	5	2	5	7	3			57
Team C - Failed	0	1	1	2	1	2	1	0	1	0	1			10
Team C - Re-check fail	0	0	0	0	0	0	0	0	0	0	0			0
Team D - Checked	1	7	7	3	10	3	2	8	4	6	3			54
Team D -Failed	0	1	0	0	1	1	1	1	0	1	0			6
Team D - Re-check fail	0	0	0	0	0	0	0	0	0	0	0			0
Team E - Checked	2	0	4	5	4	3	8	4	7	5	3			45
Team E - Failed	1	0	0	1	0	2	1	1	2	1	0			9
Team E - Re-check fail	0	0	0	0	0	0	0	0	0	0	0			0
Team F - Checked	0	2	1	2	0	1	0	1	1	6	2			16
Team F - Failed	0	1	0	1	0	1	0	0	0	0	0			3
Team F - Re-check fail	0	0	0	0	0	0	0	0	0	0	0			0
Cutting - Fail	1	0	1	0	0	0	2	0	0	0	2			6
Fusion - Fail	0	0	0	0	0	0	0	0	0	0	0			0
Button - Fail	0	0	0	0	0	0	0	1	0	0	0			1
Other- Fail	0	0	0	0	0	0	0	1	0	1	0			2

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8.1.2 Quality Rejection Rate – Calculated data

Date	Team A			Team B			Team C			Team D			Team E			Team F			All teams		
	Check	Out	RR	Check	Out	RR	Check	Out	RR	Check	Out	RR	Check	Out	RR	Check	Out	RR	Check	Out	RR
2008-03-29	37	30	18,9%	34	24	29,4%	30	25	16,7%	48	38	20,8%	20	13	35,0%	16	10	37,5%	185	140	24,3%
Week total:	**37**	**30**	**18,9%**	**34**	**24**	**29,4%**	**30**	**25**	**16,7%**	**48**	**38**	**20,8%**	**20**	**13**	**35,0%**	**16**	**10**	**37,5%**	**185**	**140**	**24,3%**
2008-03-31	31	26	16,1%	27	22	18,5%	16	13	18,8%	24	20	16,7%	17	12	29,4%	12	12	0,0%	127	105	17,3%
2008-04-01	53	39	28,3%	47	33	29,8%	53	45	15,1%	46	42	8,7%	41	28	34,1%	21	15	28,6%	261	202	23,4%
2008-04-02	55	50	10,9%	27	18	33,3%	40	36	12,5%	41	37	9,8%	34	28	17,6%	11	7	36,4%	208	176	16,3%
2008-04-03	43	36	16,3%	40	34	15,0%	36	31	13,9%	46	41	10,9%	26	19	26,9%	16	10	37,5%	207	171	17,4%
2008-04-04	55	47	14,5%	23	22	4,3%	62	54	12,9%	68	54	20,5%	40	33	17,5%	40	33	17,5%	266	225	15,4%
2008-04-05	23	18	21,7%	30	25	16,7%	25	22	12,0%	29	22	24,1%	17	13	23,5%	11	7	36,4%	135	107	20,7%
Week total:	**260**	**216**	**16,9%**	**194**	**154**	**20,6%**	**232**	**201**	**13,4%**	**254**	**216**	**15,0%**	**175**	**133**	**24,0%**	**111**	**84**	**24,3%**	**1204**	**986**	**18,1%**
2008-04-07	67	60	10,4%	42	36	19,0%	56	52	7,1%	67	56	16,4%	40	32	22,5%	22	16	27,3%	294	252	15,3%
2008-04-08	67	60	10,4%	48	45	6,3%	41	37	9,8%	34	27	20,6%	31	25	19,4%	13	13	0,0%	234	207	11,5%
2008-04-09	56	48	14,3%	48	42	12,5%	26	19	26,9%	26	21	19,2%	31	21	32,3%	15	8	46,7%	202	159	21,3%
2008-04-10	30	22	26,7%	24	21	12,5%	57	47	17,5%	54	48	11,1%	45	36	20,0%	16	13	18,8%	226	187	17,3%
2008-04-11	73	69	5,5%	66	58	12,1%	59	50	15,3%	57	53	7,0%	59	46	23,7%	16	11	31.3%	330	287	13,3%
2008-04-12																					
Week total:	**293**	**259**	**11,6%**	**228**	**202**	**11,4%**	**239**	**205**	**14,2%**	**238**	**205**	**13,9%**	**206**	**160**	**22,3%**	**82**	**61**	**25,6%**	**1286**	**1092**	**15,1%**

8.2 Appendix 2 – TSI Quality Guidelines

OPERATION 8 – Collar

Before operation:

Operation:	**Action:**
8. Collar	Check for fabric damages.
8. Collar	Check for bubbles.
8. Collar	Check style of collar on the printout (classic, business, cut-away, full spread, mao, long sleeve).
8. Collar	Check contrast fabric for collar on the printout and verify the contrast fabric.
8. Collar	Check for white collar according to printout, can be different from rest of the shirt.
8. Collar	Measure length and width and verify with printout.
8. Collar	Before attaching collar, check front placket stripe match.
8. Collar	Before attaching, cut neck curve and check collar and body, they must be the same.
8. Collar	Before attach, put the following marks: Back yoke center mark, collar line mark, collar center mark and shoulder mark.

After operation:

Operation:	**Damage:**	**How to check and avoid:**
8. Collar	Incorrect line alignment at collar point.	Both sides of the collar points should have matched lines. Fold collar and compare.
8. Collar	Incorrect outline width.	Collar hem outline should be 3/8 inch. Top outline is ¼ inch.
8. Collar	Out of shape.	Fold the shirt and place both sides of the shirt together and ensure that collar peak and collar point is the same.
8. Collar	Incorrect placement of fusion material.	Check and make sure that fusion material is placed against the upper side of the collar, not against the inside. If mao styled collar, fusion material should point to the outside of the shirt.
8. Collar	Neck shape is not identical on both sides.	Fold collar down and check the shape and make sure the collar is rounded and balanced.
8. Collar	Collar stays, pins or velbom damage.	The collar pins should be centered and point at the tip of the collar. Confirm measurement from available measurement chart.
8. Collar	Incorrect stitching.	Check for, skip or slip, open seams, broken stitch and thread matching.
8. Collar	Stain	Check for stains.

8.3 Appendix 3 – Production Data

Date	Cut-ting	Fabric Check	Fusion	Team A	Team B	Team C	Team D	Team E	Total Team	Button Attach	Final QC	Pack-ing
2/1	191	172	132	31	36	36	36	31	170	164	94	123
2/2	131	152	168	41	34	40	24	24	163	77	122	88
2/3	160	156	167	33	26	29	23	22	133	153	167	111
2/6	165	113	146	40	35	40	31	33	179	172	124	156
2/7	142	147	133	30	31	44	40	28	172	194	196	207
2/8	179	182	149	30	36	38	27	18	148	116	104	111
2/9	188	160	181	53	44	40	25	42	204	164	153	84
2/11	125	163	159	23	32	31	22	18	126	158	124	154
2/12	166	180	139	23	22	29	22	18	114	87	91	121
2/13	127	151	129	25	36	33	22	25	141	271	184	129
2/14	137	134	161	33	24	36	33	25	151	228	218	24
2/15	127	152	137	37	36	34	46	22	175	226	82	153
2/16	121	131	130	11	21	30	37	17	116	113	267	103
2/18	80	121	119	40	20	31	27	22	140	205	142	134
2/19	264	157	207	33	30	45	33	27	168	218	207	145
2/20	41	159	107	0	38	32	43	23	137	194	123	161
2/21	114	153	145	36	36	31	47	31	182	199	145	177
2/22	133	142	160	36	40	28	31	22	156	212	130	156
2/23	87	172	228	49	49	31	57	32	218	198	180	117
2/25	113	155	180	49	36	44	53	30	212	202	184	172
2/26	154	166	170	48	34	42	41	28	192	202	112	108
2/27	81	125	175	35	0	32	30	17	114	240	230	134
2/28	141	137	139	40	25	31	31	23	151	183	145	255
2/29	153	178	162	40	27	43	27	23	159	159	120	164
3/1	152	113	126	23	23	51	31	25	153	157	149	125
3/3	127	144	156	36	27	36	25	25	148	172	264	196
3/4	202	183	169	33	22	22	24	25	125	180	142	183
3/5	202	124	143	35	28	0	60	42	165	148	153	149
3/6	197	222	172	33	22	29	29	31	143	163	147	177
3/7	153	202	111	24	18	7	31	18	98	124	115	78
3/8	163	171	291	34	29	18	49	34	165	168	122	141
3/10	139	209	173	40	31	22	36	40	169	196	142	154
3/11	184	164	200	36	34	23	25	35	153	204	260	191
3/12	150	201	199	29	26	41	0	39	135	161	167	220
3/13	203	175	191	33	36	33	20	26	148	142	145	144
3/14	177	182	193	18	16	30	33	24	121	169	136	133
3/15	125	159	191	29	24	30	23	23	128	104	114	115
3/17	131	93	172	27	20	20	31	20	119	96	104	98
3/18	129	143	185	22	22	29	36	33	142	136	133	103
3/19	121	124	111	44	22	44	33	0	142	136	151	172

3/20	177	153	180	25	20	44	36	15	140	153	169	194
3/21	160	168	312	96	24	40	40	16	216	180	146	0
3/24	140	135	158	44	40	36	36	31	187	182	182	158
3/25	169	175	149	42	40	33	36	33	185	167	161	164
3/26	214	137	174	0	31	29	29	28	116	168	177	172
3/27	200	164	153	44	30	34	25	17	150	169	172	164
3/28	198	141	181	40	29	33	33	25	160	175	160	167
3/29	453	219	186	40	46	23	40	25	174	159	192	149
3/31	43	234	197	45	24	40	41	33	183	203	199	220
Total:	7628	7793	8198	1689	1433	1595	1608	1263	7587	8349	7647	7052
Avg:	156	159	167	35	29	33	33	26	155	170	156	143

9 Sources

Ahire, S., & Golhar, D. (1996). Development and validation of TQM implementation. *Decision Sciences, Vol 27* , 23-56.

Anderson, D. (2004). *Build-to-order & Mass Customization: The Ultimate Supply Chain.* CIM Press.

Andersson, E., & Fornell, C. (1994). Customer satisfaction, market share, and profitability. *Journal of Marketing vol 58* , 53-66.

Andersson, R., & Eriksson, H. (2006). Similarities and differences between TQM, six sigma and lean. *TQM Magazine* .

Anupam, D., & Swierczek, F. (2008). Developing and validating total quality management (TQM) constructs in the context of Thailands manufacturing industry. *Benchmarking, An International Journal, Vol 15* , 52-72.

Bell, J. (2000). *Introduktion till forskningsmetodik* . Lund, Sweden: Studentlitteratur.

Blocher, J. D., & Chajed, D. (2007). Minimizing customer order lead-time in a two-stage assembly supply chain. *Springer Science Business Media* .

Brown, M., & Hitchcock, D. (1994). *Fails and What to Do about It.* Burr Ridge: Irwin.

Dahlgaard, J., & Dahlgaard-Park, S. (2006). Lean production, six sigma, quality, TQM and company culture. *The TQM Magazine* , 263-281.

Davis, S. (1987). *Future Perfect, Reading.* Reading: Addison-Wesley.

Deming, E. (1988). *Out of the crisis.* Cambridge University Press.

Dettmer, W. (1998). *Breaking the Constraints to World-class Performance.* American Society for Quality.

Dettmer, W. (1997). *Goldratt's Theory of Constraints: A Systems Approach to Continuous Improvement.* American Society for Quality.

Dettmer, W. (1995). Quality and the theory of constraints. *Quality Progress* , 77-82.

Duray, R. (2000). Approaches to mass customization: configurations and empirical validation. *Journal of Operations Management* , 605-625.

Duray, R. (2002). Mass customization origins; mass or custom manufacturing? *International Journal of operations & production management* , 314-328.

Duray, R., & Ward, P. (2000). Approaches to mass customization: configurations and empirical validation. *Journal of Operations Management* , 605-625.

Eisenhart, M. (1989). Building Theories from Case Study Research. *Academy of Managment Review, Vol 14* , 532-550.

Ekengren, A.-M., & Hinnfors, J. (2006). *Uppsatshandbok – Hur du lyckas med din uppsats.* Lund, Sweden: Studentlitteratur.

Eskildson, L. (1994). Improving the odds of TQM’s success. *Quality Progress, Vol. 27 No. 4* , 61-63.

Fuchs, C., & Kenett, R. (1998). *Multivariate Quality Control: Theory and Applications.* CRC Press.

Ganesan, R. (2008, 02 22). Quality Supervisor, Tailor Store International. (D. Estephan, & T. Uppström, Interviewers)

GAO. (1991). *Management practices: US companies improve performance through quality efforts.* Washington DC: US General Accounting Office.

Gilmore, J., & Pine, J. (1997). The four faces of mass customization. *Harvard Business Review* .

Goetsch, D., & Davis, S. (2003). Overview of total quality tools. *Processing and Services* .

Goldratt, E., & Cox, J. (1984). *The Goal.* North River Press.

Harari, O. (1997). Ten reasons why TQM doesn't work. *Management Review, Vol. 86 No. 1* , 38-44.

Hart, C. (1994). Mass customization - conceptual underpinnings, opportunities and limits. *International Journal of Service Industry Management* , 36-45.

Hellsten, U., & Klefsjö, B. (2000). TQM as a management system consisting of values, techniques and tools. *TQM Magazine* , 238-244.

Hoyer, R. W., & Hoyer, B. (2001). What is quality? *Quality Progress* , 52.

Husby, P. (2007). Competition or Complement: Six Sigma and TOC. *Material Handling Management* , 51-55.

Höjman, J. (2008, 01 23). CEO, Tailor Store Sweden. (D. Estephan, & T. Uppström, Interviewers)

Jacobsen, D. (2002). *Vad, hur och varför? – Om metodval i företagsekonomi och andra samhällsvetenskapliga ämnen.* Lund, Sweden: Studentlitteratur.

Joel, R. (1999). *Total Quality Management: Text, Cases and Readings.* CRC Press.

Juran, J. T. (1989). *Leadership for Quality: An Executive Handbook.* New York: The Free Press.

Juran, J., & Gryna, F. (1993). *Quality Planning and Analysis.* New York: McGraw-Hill.

Kotha, S. (1996). From Mass Production to Mass Customization: The Case of the National Industrial Bicycle Company of Japan. *European Management Journal* , 442-450.

Kotler, P. (1989). From mass marketing to mass customization. *Planning Review* , 10-15.

Kumar, A. (2004). Mass Customization, Metrics and Modularity. *The International Journal of Flexible Manufacturing Systems* , 287–311.

Kumar, S., & Gupta, Y. (1991). Cross functional teams improve manufacturing at Motorola's Austin plant. *Industrial Engineering, Vol. 23 No. 5* , 32-36.

Körner, U. (2003). *Köteori.* Studentlitteratur.

Loodberg, M. (2008, 01 23). Financial Director, Tailor Store Sweden. (D. Estephan, & T. Uppström, Interviewers)

Nalin, P. (2008, 02 19). CEO Tailor Store International. (D. Estephan, & T. Uppström, Interviewers)

Nave, D. (2002). How To Compare Six Sigma, Lean and the Theory of Constraints. *Quality Progress* , 73-78.

Ohno, T. (1988). Toyota Production System: Beyond Large-Scale Production. *Productivity Press* .

Pine, J., & Davis, S. (1999). *Mass Customization: The New Frontier in Business Competition.* Harvard Business School Press.

Priyantha, B. (2008, 02 19). Production & Quality Supervisor, Tailor Store International. (D. Estephan, & T. Uppström, Interviewers)

Proctor, T. (1999). Creative Problem Solving for Managers. *London, UK:Routledge* .

Radder, L., & Louw, L. (1999). Mass customization and Mass Production. *The TQM Magazine* , 35-40.

Shiroma, R. (2008, 02 19). General Manager, Tailor Store International. (D. Estephan, & T. Uppström, Interviewers)

Shyamalie, R. (2008, 02 19). Production & Communication Manager, Tailor Store International. (D. Estephan, & T. Uppström, Interviewers)

Sila, I., & Ebrahimpour, M. (2000). An investigation of the total quality management survey based research published between 1989 and 2000: a literature review. *International Journal of Quality Management, vol 19, No. 7* , 902-970.

Silveira, G., & Borenstein, D. (2000). Mass customization - literature review and research directions. *International Journal of Production Economics* , 1-13.

SIME. (2008). *SIME*. Retrieved 01 25, 2008, from www.sime.nu

Ström, M.-O. (2008, 01 23). Creative Director, Tailor Store Sweden. (D. Estephan, & T. Uppström, Interviewers)

Svensson, S., & Barfod, A. (2002). Limits and Opportunities in Mass Customization for build to order SMEs. *Computers in Industry* , 77-89.

Tseng, M., & Jiao, J. (2001). *Mass Customization, in G. Salvendy (Ed.) Handbook of Industrial Engineering, 3rd edition.* New York: Wiley.

Ulrish, P., & Anderson-Connell, L. J. (2003). Consumer co-design of apparel for mass customization. *Journal of Fashion Marketing and Management* , 398-412.

Waldman, D. (1995). What is TQM research? *Canadienne des Sciences de l'Administration* , 4.

Watson, K., & Blackstone, J. (2007). The evolution of a management philosophy: The theory of constraints. *Journal of Operations Management* , 387-402.

Womack, J., & Jones, D. (1990). *The Machine that Changed the World.* Rawson Associates.

Zipkin, P. (2001). The Limits of Mass Customization. *MIT Sloan Management Review* , 81.