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Quality performance and cost analysis within customized production

- Two case studies from the worktop industry

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Preface

This master thesis concludes our Master of Science educations within *Industrial Engineering and Management* and *Mechanical Engineering* at Lund University. The master thesis corresponds to 30 ECT credits and was performed during 20 weeks, September 2011 – January 2012. The master thesis was commissioned by IKEA of Sweden and conducted at the IKEA Trading office in Dortmund, Germany.

Firstly, we would like to thank our supervisor at IKEA Trading, Uwe Lange, the Deputy Trading Area Manager, Peder Elfving, as well as IKEA personnel in Dortmund for great feedback and support.

Secondly, we would like to thank our supervisor at IKEA of Sweden, Fredrik Nilsson, for the opportunity to perform the project in Germany under such supporting circumstances.

Thirdly, we would like to thank all personnel at Lechner and Danform for their openness and willingness to bring the project further. This report had not been possible without your valuable help and assistance. Thank you.

Finally, we would like to address a special thanks to our supervisors at Lund University, Adjunct Assistant Professor Bertil I Nilsson and Professor Jan-Eric Ståhl, for invaluable support, great guidance and quick direct responses throughout the master thesis.

We are truly pleased to have had the opportunity of finishing our Master of Science educations within such an interesting field under such supporting circumstances. We hope that this master thesis will further strengthen the relationship between IKEA and the suppliers, and we wish all three participants the best for the future.

Lund, January 2012

Christoffer Möller & Anders Sahleström

Abstract

Title	Quality performance and cost analysis within customized production - Two case studies from the worktop industry
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Supervisors	Uwe Lange, IKEA Trading, Dortmund Bertil I Nilsson, Division of Production Management, Lund University Jan-Eric Ståhl, Division of Production and Materials Engineering, Lund University
Keywords	Cost Break Down, Cost Of Poor Quality, Critical To Quality, Production Performance Matrix, Root-Cause Analysis, Systematic Production Analysis, Total Quality Management
Purpose	The purpose is to increase the IKEA knowledge regarding production of custom made worktops at two German suppliers, providing an action plan for the suppliers of how to increase product quality as well as calculating the potential cost savings and the product cost structure.
Methodology	The project is performed as two case studies, where both qualitative and quantitative data has been obtained through literature reviews, interviews, observations, provided data and data collections.
Results	The results showed that in order to increase product quality, the suppliers must take actions within the following areas: *Lechner* must increase operator involvement, improve the measurement system, increase structure and coordination between departments, implement control through documentation and increase the management commitment to quality. *Danform* must increase operator involvement, improve the method of product control and structure quality work regarding continuous improvements. Depending on the actual claim rate, if product quality is increased, the suppliers' cost savings potential within the manufacturing, is for Lechner between 258 000-920 000 € and for Danform between 175 000-650 000 €. Similarities of the specific cost structures of both suppliers' custom made worktops indicated that the material cost had the biggest impact on the total manufacturing cost. Furthermore, the sum of material and wage costs always composed of more than 75 % at Lechner, and 80 % at Danform, of the total manufacturing cost.

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1 Introduction

In this chapter, the background, the problem description and the delimitations are presented together with the master thesis purpose and outline. This is to be used as guidance throughout the master thesis.

1.1 Background

According to IKEA, when purchasing a kitchen, the customer of today requires a greater possibility of customization than before. This entails an increasing demand of custom made kitchen components. Custom made worktops, also known as the IKEA PERSONLIG range, are part of the kitchen range at IKEA of Sweden (IOS), and sets a unique mark by enabling customers to choose the exact design of the worktops for their kitchens. The PERSONLIG range offers e.g. the possibility to join worktops in a kitchen corner as well as to create customized kitchen islands.

Each custom made worktop is uniquely formed by customer demand, and can be modified from plenty of choices and varieties, such as shapes, colors and four different materials. A custom made worktop is designed according to customer requirements by an IKEA seller at an IKEA department store, from where the order is sent directly to the worktop supplier.

IKEA sources its custom made worktops, non-branded, from two suppliers in Germany; *Lechner* and *Danform*. Both suppliers produce directly to order for IKEA, according to each unique drawing and customer order. This obliges an effective combination between lead-time and production efficiency, as well as implying limited possibilities of long term planning. The versatile nature of the product also requires flexibility within the single-unit production setup, where vast possibilities of customization are needed. Since the first manufacturing stage at the supplier is not initiated until customer order has been received, production flows have to be adapted to each customer order.

IKEA suffers from quality issues within the PERSONLIG range. These quality problems correspond to one of the highest claim rates at IKEA, resulting in a high cost of poor quality (COPQ). IKEA categorizes the causes of these quality issues as sales mistakes by IKEA, damages during transportation and production mistakes at supplier facilities. This master thesis regards the quality problems that can be ascribed to the suppliers.

1.2 Problem description

According to IKEA, the claim rate ascribed to each supplier corresponds to approximately 4 % of produced customer orders. Quality issues within customized production denotes as difficult to determine, due to the flexibility of the single-unit production setup. Since the PERSONLIG range is not aligned with other IKEA mass produced products in terms of handling, IKEA must deepen its knowledge of the product, the production and the root-causes of quality problems.

The key questions of this master thesis are the following:

- What are the root-causes of poor product quality in the production at Lechner and Danform and how can these be prevented?
- What is the economic effect of each root-cause, if it is prevented?
- What is the cost structure of a custom made worktop?

1.3 Delimitations

Due to the large scale of the project, numerous theoretical areas as well as the geographical distance between the project participants, the key questions must be delimited. The following delimitations are stated in order to frame the project and investigate prioritized areas:

- The project stretches from order receiving to packaging at supplier facilities. This implies that neither areas such as digital order transferring between IKEA and supplier, nor final transportation and logistics between supplier and end customer, are of interest.
- Investigated materials are laminate and solid wood.
- A comparison of supplier quality performance will not be made.
- The economic effects are limited to the suppliers' cost savings potential within the manufacturing.

1.4 Purpose & objectives

The purpose of this master thesis is to increase the IKEA knowledge regarding production of custom made worktops. The primary objective is to provide IKEA with the answers to the key questions, in order to increase the level of quality in the suppliers' part of the PERSONLIG supply chain.

The secondary objective is to perform a quality and production evaluation of both suppliers, providing them with an action plan of how to increase product quality and reduce manufacturing costs.

Deliverables are the identified root-causes together with preventive actions, cost savings calculations if product quality is improved and a cost structure analysis of custom made worktops.

1.5 Target group

The first target group is IOS in Älmhult and IKEA Trading in Dortmund. The second target group is Lechner and Danform, who will each receive a modified version of the master thesis, not revealing confidential information of one another. The third and final target group is students and employees at the Faculty of Engineering at Lund University.

1.6 Company restricted material

To maintain a desired level of secrecy, sensitive data used for calculation has not been presented. Nevertheless, no alteration of figures, values, results and conclusions have been made.

1.7 Advice to the reader

Throughout the master thesis, interviews and measurements have been conducted in both English and German. To facilitate the usage of the report, for both IKEA and the suppliers, some words are kept in their original language. A German-English dictionary as well as explanation of work stations is therefore placed at the reader's disposal in chapter 10.7 and Appendix 2 respectively.

1.8 Report outline

The report has a traditional outline in order to give the reader a clear understanding of the structured approach and progress of the master thesis.

1.8.1 Methodology

The methodology chapter describes the selection of approaches and methods as well as their applications in order to answer the key questions of the master thesis. The project structure with data collection as well as the quality of the project is explained.

1.8.2 Theory

The theory chapter can be divided into four major sections; quality management, manufacturing and manufacturing cost model, supply chain management and process management. Quality concepts, quality frameworks and COPQ are explained in the quality section. The manufacturing section explains fundamental manufacturing concepts together with frameworks for production quality and economy. Supply chain management and process management are concisely explained in the third and fourth section of the chapter.

1.8.3 Empirics

The empiric chapter covers the description of the product, IKEA, Lechner and Danform. Each supplier is separately presented reviewing manufacturing processes, manufacturing layout, production flows as well as quality work.

1.8.4 Modification and application of manufacturing frameworks

This chapter describes the modification and implementation of the manufacturing frameworks. Modifications were performed to better suit IKEA and the suppliers.

1.8.5 Analysis

The analysis chapter combines all preceding chapters, where each supplier is analyzed separately. The analysis is composed within areas referring to the key questions of the master thesis.

1.8.6 Results and conclusions

This chapter aims at answering the key questions of the master thesis with the analysis chapter as a foundation.

1.8.7 Discussion

The discussion chapter contains recommendations to both IKEA and the suppliers and discussions regarding project execution as well as areas of improvements and further investigations.

1.8.8 Contribution to academia

This chapter concludes the master thesis and presents the contributions made for academic and research purposes.

2 Methodology

In this chapter, the research approach, work methods and project structure are presented. The chapter also highlights data collection, validity, reliability and criticism of sources.

2.1 The research approach

The methodology of choice should work as a guide and foundation throughout a project. The method will not serve the purpose of answering how and when things should be done. Instead, it is a high level tool that should transform the first overall objectives into a specific work path. The choice of method depends on the goals and characteristics of the project (Höst, Regnell & Runeson, 2006, p 29). The research approach can be summarized as three different approaches (Gammelgaard, 2001, p 481):

- **The analytical** – The reality is objective and the researcher must not influence the research object. This implies a decomposition of the reality into elements, turning elements into concepts and revealing cause and effect relations.
- **The systems approach** – The world must be understood in terms of mutually depended components. The mission of the researcher is to investigate a smaller fragment, identifying parts, links and goals. This is done by looking at different cases rather than decomposing elements.
- **The actors approach** – This approach claims that the reality is not objective, but is the result of various social constructions. Therefore, it is impossible to predict results due to the human factor.

The three approaches towards reality and their relations towards theory, methods and the position of the researcher can be categorized as shown Figure 2-1. The approach of the researcher will therefore have a big impact on other research considerations (Gammelgaard, 2001, p 482). In this master thesis, a systems approach has been chosen.

	Systems approach	Systems approach	Actors approach
Theory type	Determining cause-effect relations. Explanations, predictions. Universal, time and value free laws	Model. Recommendations, normative aspects. Knowledge about concrete systems	Interpretations, understanding. Contextual knowledge
Preferred method	Quantitative (qualitative research only for validation)	Case studies (qualitative and quantitative)	Qualitative
Unit of analysis	Concepts and their relations	Systems: links, feedback mechanisms and boundaries	People – and their interaction
Data analysis	Description, hypothesis testing	Mapping, modelling	Interpretation
Position of the researcher	Outside	Preferably outside	Inside – as a part of the process

Figure 2-1: The different approaches and their relations (Gammelgaard 2001, p 482).

2.1.1 The four research purposes

There are four research purposes for a project, described below (Höst, Regnell & Runeson, 2006, p 29):

- **Descriptive studies** – The purpose of the study is to examine and describe the function or the execution of a certain subject field.
- **Exploratory studies** – The purpose of the study is to go deeper within a certain subject field.
- **Explanatory studies** – Studies that try to find explanations, causes and links in order to determine how a certain subject field is executed.
- **Problem solving studies** – The purpose of the study is to find a solution to a given problem. The researcher reveals different key questions, action plans and their consequences.

In this master thesis, a problem solving purpose has been chosen.

2.1.2 The four research methods

There are four research methods that are suitable for a master thesis. The research approach determines which one to choose (Höst, Regnell & Runeson, 2006, p 30).

A survey is a collection of data, within a certain area, in order to transform a general picture. The survey tends to be formed as fix, meaning that there will be no changes or additions to the project description. It is possible to work with hypotheses, but no links and causes can be studied (Höst, Regnell & Runeson, 2006, p 31).

Case studies are used to explore areas on a deeper level without affecting the studied object. These are used e.g. to understand how an organization is executing its tasks. It is possible to study two cases or more during the same period, but there are no intentions to generalize the conclusions in order to be valid on a broader scale (Höst, Regnell & Runeson, 2006, p 33).

In experiments, certain alternatives are studied in order to identify a couple of factors. These factors are tested in order to find correlations and develop a final result. This is mostly done when trying to find causes to specific problems as well as links between different factors (Höst, Regnell & Runeson, 2006, p 36).

The action research is a well-documented activity in order to solve a specified problem. It is a combination of studying and solving the problem, with the purpose to improve the activity. The method starts with observations in order to frame the problem, then finding the solution followed by an implementation. The method is similar to quality improvements and the plan-do-check-act cycle (Höst, Regnell & Runeson, 2006, p 39).

In this master thesis, the method of choice is case studies. Due to the short time frame, neither the experiment method nor the action research method could be applied, since neither repeat of experiments nor implementation could fit into the project time frame.

2.2 Data collection

The master thesis requires collection of data within different fields. These are described below. The phenomena can be described as a triangulation; the practice of viewing the surroundings from more than one perspective in order to give the researcher a better total understanding. This includes different methods, data collections and sources as well as different researchers (Denscombe, p 346) and might lead to improved accuracy and a holistic perspective. However, it is more time demanding and requires a multi-skilled researcher (Denscombe, p 349).

2.2.1 Qualitative & quantitative methodology

Quantitative data can be represented in terms of numbers and values. The analysis of quantitative data is often based upon statistic methods. It can be used to explore collected data or to determine links, causes and hypotheses. Qualitative data can be represented as words, thoughts, interviews and descriptions. It can be examined by the existence and frequency of e.g. words in an interview. One should not draw any statistical conclusions from a qualitative analysis, but one can e.g. determine the motivation for certain answers in order to explore the data on a deeper level (Höst, Regnell & Runeson, 2006, p 110-111).

Traceability is of high importance when dealing with qualitative conclusions. The source, e.g. a quote or a phrase, must be clearly stated and the reviewers must be able to examine its origin (Höst, Regnell & Runeson, 2006, p 114-116). However, a balance between qualitative and quantitative approaches must be considered. The nature of the phenomena and the addressed question will affect the information that the researcher can receive, consequently influencing the research method (Golicic, Davis & McCarthy, p 20). Researchers who choose only one approach will delimit the scope of their inquiry (Golicic, Davis & McCarthy, p 26).

This master thesis includes both quantitative and qualitative data. However, due to a lack of quantitative data, the qualitative data collection has been of great importance.

2.2.2 Literature review

A literature review is a quick way to gather information. However, with a short time frame it is necessary to state what could be of interest as early as possible. Another strategy is to have a clear idea of what is *not* of interest (Bell, 2000, p 62). A literature review is also important to capture already known knowledge (Höst, Regnell & Runeson, 2006, p 59).

In order to get on the right track from the beginning, the two supervisors from Lund University have suggested the literature in the start-up-phase. The thesis authors have throughout the project added further literature of interest. Comprehension of knowledge from four main fields was considered essential for the master thesis execution, presented in chapter 3. The chosen fields and their theoretical contribution are described below. The two first-mentioned fields were used to a greater extent when answering the key questions of the master thesis. The two latter fields are related to understand the supplier and product surroundings as well as to establish a foundation of the master thesis execution.

- **Quality management**– Chapter 3.1 contains the major quality theories and concepts in order to obtain a complete and broad understanding of quality approaches.
- **Manufacturing and manufacturing cost model** – Chapter 3.2 contains manufacturing basics as well as profound theories within chosen manufacturing performance approach and manufacturing cost model. There are not many manufacturing cost models of choice. Therefore, the thesis authors decided to investigate and use the manufacturing theories recommended by one of the supervisors.
- **Supply chain management** – Chapter 3.3 contains supply chain management basics as well as specific theories regarding the suppliers' supply chain.

- **Process management** – Chapter 3.4 contains process management basics in order to execute the master thesis from a process perspective.

2.2.3 Interviews

An interview is needed to gather information that is not listed or registered. An interview can be stated as a couple of questions to the person of interest. There are different kinds of interviews and Höst, Regnell and Runeson (2006, p 89-91) describe them as following:

- **An open interview** does not have pre-specified questions. Instead, the interviewer has different areas of interest for further investigation. One must be aware of the fact that the discussion will be formed after the willingness of the interviewed person; the areas that this person would like to address will be given most time. In order to cover all fields of interest, the interviewer can set a minimum time frame given each area.
- **The half structured interview** is a mixture of open questions within different areas and specific questions specified in advance. In each interview, it is truly important to ask the specific questions in the same order and with the same formulations, in order to validate and compare the answers.
- **The structured interview** can be regarded as an oral survey, with each question clearly stated since the interviewer knows exactly what information to obtain.

This master thesis has used all three interview methods; in most cases the open and half structured interview. In general, open questions have been addressed in the early stage of the master thesis, and structured questions towards the final part. In order to obtain required and reliable information, chosen respondents have been production operators, department personnel, department managers and top management. Most of the information in the empiric chapter 4 has been collected through interviews. Exceptions where other empiric sources have been used are described in chapter 2.2.4, 2.2.5 and 2.2.6. Also, performance of a process walk through, explained in chapter 3.4.3, was partly performed through interviews.

Good interview advices that the thesis authors have been taken into account are described below:

- To have an agreements regarding what to discuss (Häger, 2004, p 22).
- To avoid words with individual and different meanings (Häger, 2004, p 26).
- To think before one asks, talk around the subject (Häger, 2004, p 30).
- However, when one would like a straight answer, ask a specific question (Häger, 2004, p 31).
- To focus on the primary question (Häger, 2004, p 35).
- To listen is of great importance (Häger, 2004, p 78).

2.2.4 Observations

There are two types of observations: Participating and non-participating observations. In the case of participating observations, the researcher tries to be accepted in the group or within the activity of observation. This method generates hypotheses, but is time requiring and the start-up-phase usually does not have specified observation factors. Non-participating observations have a clear stated description of what to observe (Bell, 2000, p 137).

Throughout the master thesis, non-participating observations have been performed due to the nature of the project. Collection of some manufacturing parameter values, described in chapter 3.2.3, was performed through observations. Part of the performance of a process walk through, explained in chapter 3.4.3, was executed through observations and used in order to map and document the order process at each supplier, described in chapter 4.3.2 and 4.4.2. Observations were also used to map and document the production flows at each supplier, explained in chapter 4.3.3.2 and 4.4.3.2.

2.2.5 Provided data

Part of the values for manufacturing parameters, described in chapter 3.2.3, have been provided by the suppliers, and the economic data, described in chapter 3.2.3, have been provided by IKEA and one of the suppliers. Part of the data used in the empiric chapter 4.1 has been provided by IKEA as well as the complete IKEA supplier quality standard (IKEA SQS), explained in chapter 4.2.5. Also, information for chapter 4.4.6 has been provided by the supplier.

The reliability and validity of this data have strongly been taken into consideration before it has been used.

2.2.6 Data collection forms

A survey can be used to collect information and opinions from a larger group of individuals. The foundation of how to construct a survey lies within the selection of the respondents. There are some guidelines about the spread of a specific survey (Höst, Regnell & Runeson, 2006, p 85-86).

- **Total research** – All individuals in the population.
- **Random selection** – A randomly selected part of the population.
- **Systematic approach** – According to a certain periodicity, e.g. every 20th person.
- **Cluster selection** – If the population is divided into clusters, choose the cluster of interest and use another method within that cluster.
- **Stratified selection** – When the clusters differ, they are first separated by their characteristics and the respondents are then chosen by using another method.

In the master thesis, data collection forms have been used in the manufacturing, with manufacturing personnel as respondents, in order to collect production data concerning quality as well as part of the manufacturing parameters presented in chapter 3.2.3. The information from the data collection is analyzed in chapter 6.1.1 and 6.2.1, and the total summary of the data collection forms can be found in Appendix 3.

2.3 Validity & reliability

The researcher must always examine the collected information as well as the results, no matter the method of choice. This is called validity and reliability (Bell, 2000, p 89).

2.3.1 Validity

Validity is a quite complex term. It shows if the factors that are measured or observed truly answer the questions of interest. A statement can be reliable but not valid, but if reliability is missing, so is validity. It is seldom necessary to go deeper in the technical aspects of validity in a smaller project (Bell, 2000, p 90). Validity can also be explained as the connection between the object of interest, and that what is actually measured (Höst, Regnell & Runeson, 2006, p 42).

The validity of this master thesis is discussed in chapter 8.

2.3.2 Reliability

The reliability of a project means that the same result should be achieved, if the project is to be repeated under the same circumstances (Bell, 2000, p 89). According to Höst, Regnell and Runeson (2006, p 41), reliability can be defined as the trustfulness in data collection, if random varying variables are taken into account. The reliability can be secured by performing the data collection with accuracy, describing the collection procedure of the data as well as authorizing a third part to review the material (Höst, Regnell & Runeson, 2006, p 42).

The reliability of this master thesis is discussed in chapter 8.

2.3.3 Primary & secondary sources

Sources can be categorized as primary or secondary sources. **A primary source** is a direct source that is collected during the progress of the project, divided into two subgroups: Purposeful or non-purposeful sources. A purposeful source is a document written to explain a certain point of view or store information for future usage. A non-purposeful source can be used in other purposes than it was originally created for; suitable data can be chosen. This implies that these kinds of sources tend to be more open than the purposeful ones (Bell, 2000, p 94-95).

A secondary source is an interpretation of information, normally based on a primary source. It can be difficult for the researcher to distinguish between these two, and participants may have different opinions regarding what to consider primary or secondary (Bell, 2000, p 94).

In this master thesis, the theory chapter has stated sources, whereas in the empiric chapter, no sources are stated due to two main reasons. Firstly, some information gathering for the empiric chapter required numerous sources, implying a difficulty in stating the main source. Secondly, the thesis authors have been striving towards an objective result, and have therefore decided not to state answers of individual respondents as references.

2.3.4 Criticism of sources

It is truly important to be aware of the reliability of sources. It is crucial to distinguish between a certain opinion and reviewed scientific facts (Höst, Regnell & Runeson, 2006, p 60). The analysis of sources can be divided into extern and intern analysis (Bell, 2000, p 98-99). Extern analysis aims to determine if the source is real and reliable. It is important to investigate the origin of the source to assure its credibility. Intern analysis is more common within smaller projects. The purpose is to secure content reliability of the source. This is done by questioning the true meaning of the source, investigating under what circumstances the information was revealed and if the information has been manipulated (Bell, 2000, p 99).

2.4 Project quality

What needs to be considered as necessary project quality parameters depends on the art of the project as well as for whom it is performed (Höst, Regnell & Runeson, 2006, p 76-79). In order to ensure project quality, the thesis authors have taken the following areas into consideration:

- **Suitability** – The capability of the suggested solutions.
- **Usability** – Making sure that the solutions can be of use.
- **Understandability** – The solutions should not be too tricky or advanced in order to work.

- **Efficiency** – The solutions should focus on areas where they can be used efficiently.

2.5 Project structure

The project structure is described in Figure 2-2, containing the following 8 steps, where steps 3-8 were executed at each supplier respectively.

1. Literature review of fundamental theories and frameworks.
2. Understanding of the IKEA organization, the customer order process at an IKEA department store, the work structure at IKEA Trading Dortmund and systems and documentation regarding the PERSONLIG range.
3. Mapping of the process from order receiving to production hall.
4. Mapping of production flows in the manufacturing.
5. Conducting measurements at work stations by executing a systematic production analysis as well as data collection for cost structure calculations.
6. Analysis of measurement results and interviews with supplier personnel.
7. Execution of deeper structured interviews with responsible department managers.
8. Combining of measurements and interviews in order to capture differences between work performance and stated work procedures regarding quality and improvements. Also, cost structure calculations and forming of results and conclusions.

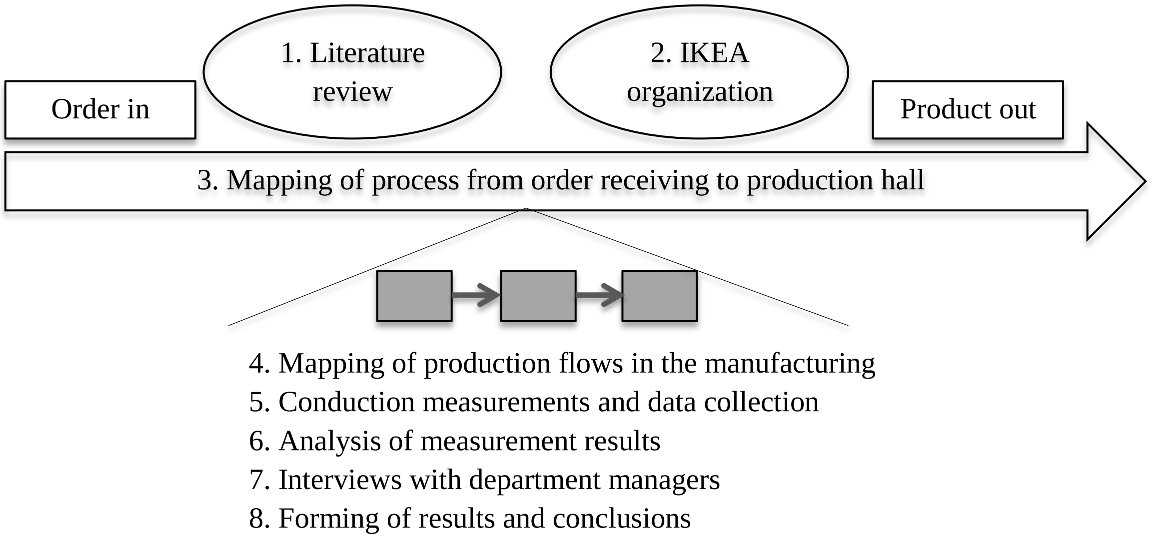


Figure 2-2: The project structure of the master thesis (Möller & Sahleström, 2011).

3 Theory

In this chapter, theoretical frameworks for the master thesis are presented. Both general and specific theories are covered including quality management, manufacturing and manufacturing cost model, supply chain management and process management. Presented theories shall deepen the understanding within required subject fields.

3.1 Quality management

3.1.1 The definition of quality

There are vast definitions of quality. A product can be *suitable for its purpose of use*; however this definition is often too narrow and processes before reaching the end customer are not taken into account. A product should have such quality that is suitable for all the subsequent processes, regardless if it is manufacturing, transportation or the end user (Sandholm, 2008, p 13). Though, the product must not only be suitable, it must also fulfill the end customer requirements. Therefore, one quality definition is stated as *the product capability to meet the customer needs, needs that can be spoken, implicit or unconscious* (Sandholm, 2008, p 14). Definitions that are generally too narrow are *conformance to requirements* and *fitness for use*. These definitions are insufficient since the producer often states the product requirements without end customer interaction (Sörqvist, 2000, p 11). The international standard ISO 9000 defines quality as *the degree to which a set of inherent characteristics fulfills the requirements, i.e. needs or expectations that are stated, generally implied or obligatory* (Bergman, Klevsjö, 2010, p 21-23). Bergman and Klevsjö (2010, p 23) contend that the ISO 9000 definition must be further expanded, defining quality as *the ability of a product to satisfy, or preferably exceed, the needs and expectations of the customer.* This implies that companies must frequently exceed customer expectations in order to obtain loyal customers and future success. Oakland (2004, p 5) highlights that quality and reliability are linked. A customer will evaluate a product regarding its function over time. Also, by constantly exceeding the customer requirements, it is possible to go from fulfilling customer requirements to delighting the customer. In the long run, this is how loyalty is created. The different definitions are summarized in Figure 3-1, presented below.

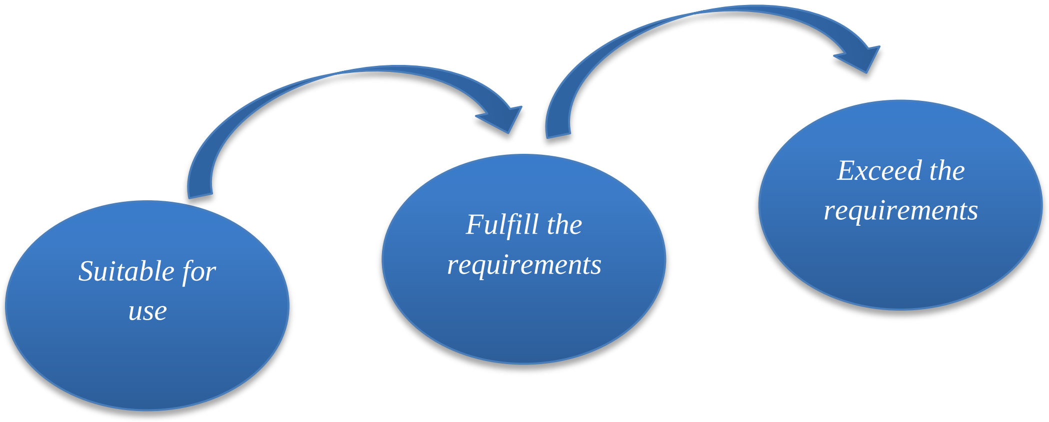


Figure 3-1: The evolution of definitions of quality (Möller & Sahleström, 2011).

In the 1980s, David A. Garvin presented five perspectives to broaden the definition of quality, claiming that quality must be seen through all five perspectives in order to fully understand the concept of quality and its significance for different departments within an organization (Bergman, Klevsjö, 2010, p 25):

- **The transcendent perspective** – Quality lies in the eye of the beholder and can not be defined before it is experienced.
- **The product based perspective** – Quality is exactly measurable and is defined as how well the product processes secure required characteristics.
- **The user based perspective** – Quality is judged by the customer and must fulfill the customer needs and expectations.
- **The manufacturing based perspective** – Quality is related to tolerances and requirements in the production, where better quality implies less scrap.
- **The value based perspective** – Quality is defined as the balance between performance and cost. A product must obtain the quality attributes, but to a reasonable cost.

There are two dimensions that can be distinguished regarding quality work. *To manage, control and secure* imply activities performed in order to maintain a certain level of quality. D*evelopment and improvements* refer to initiatives, projects and actions taken to increase this level (Sörqvist, 2004, p 27). Figure 3-2 visualizes the dimensions. The wedge symbolizes a quality management system (QMS) that secures the efforts and improvements the company has executed, symbolized by the round circle. With no system for documenting and securing the made efforts, improvements will not be permanent.

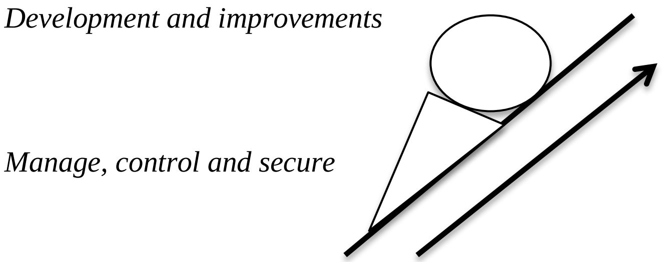


Figure 3-2: The two dimensions of quality work (Sörqvist, 2004, p 27).

3.1.2 Customers

The customer concept is essential within quality theory, due to the definitions stated in 3.1.1. Bergman & Klevsjö (2010, p 27) define customers as *the people or organizations that are the reason for a company's activities and for whom the company wants to create value*. Sörqvist (2000, p 29) states that earlier definitions such as *the receiver of a product* or *for whom the organization exists* are too narrow, suggesting the customer definition to be *everyone that in some way is affected by a business, product or service that a company produces or provides*. Sandholm (2008, p 16) also concludes that the definition of customers, as *everyone that is affected by the business of a company,* well reflects the customer concept of today.

Customer concepts can be divided into *internal and external customers*. Oakland (2004, p 8) refers this as *the quality chain*. Within each department, company or supply chain, there are series of suppliers and customers. As illustrated in Figure 3-3, these suppliers and customers make up quality chains, which at any moment can be broken due to poor quality of a product or information. Oakland (2004, p 8) states that a major issue within many businesses is that quality problems are often detected in the interface between the end customer and the organization, and not throughout the internal quality chain.

Also, Bergman & Klevsjö (2010, p 39) highlight the importance of not only focusing on external customers, by underlining the risk of ignoring the internal customers, their needs and requirements due to the strong external customer focus within Total Quality Management (TQM), explained in chapter 3.1.3.

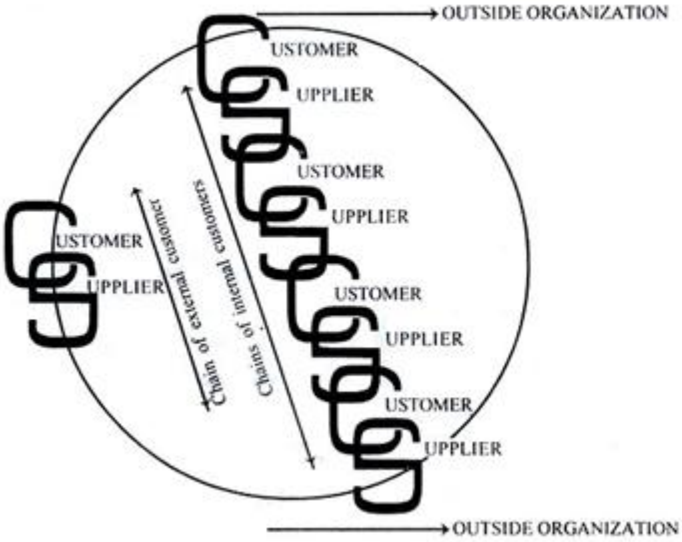


Figure 3-3: The quality chain concept (Oakland, 2004, p 8).

Customer needs are, together with the customer concept, essential to fully understand the quality definition. The Kano model describes how customer satisfaction is generated based upon customer needs. The model distinguishes three distinct customer needs that a company should try to fulfill, shown in Figure 3-4 (Sandholm, 2008, p 18-19).

The basic needs are seen as so fundamental and obvious that they must not be stated in product or service requirements. Fulfilling the needs will not lead to increased customer satisfaction, but if lacking, the customer dissatisfaction might increase heavily (Sandholm, 2008, p 18).

The performance needs are needs that the customer holds as important and expects to be fulfilled. When fulfilling the stated needs, the customer will be satisfied (Sandholm, 2008, p 19).

The excitement needs mean that the customer satisfaction increases when a product fulfills a not stated or considered requirement, which increases the product value. However, when the needs are known, they will be part of the performance needs (Sandholm, 2008, p 19).

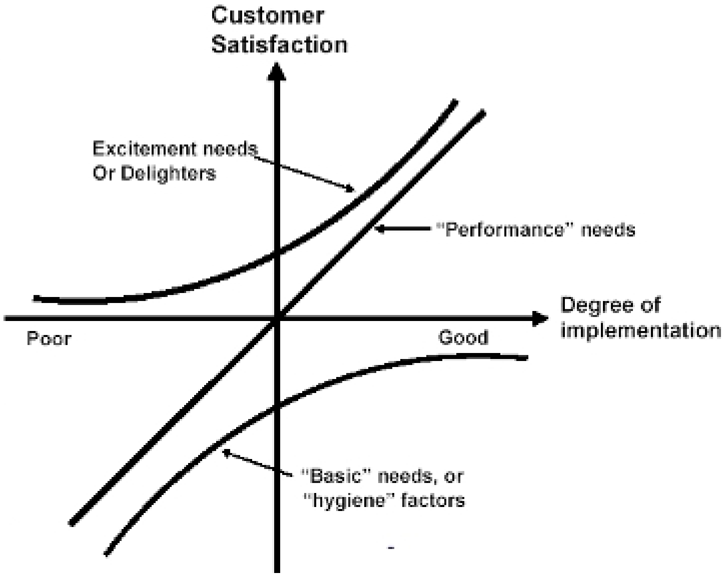


Figure 3-4: The Kano model describing the distinct customer needs (Sandholm, 2008, p 16).

Customer expectations can have a high impact on the overall customer satisfaction. There are two different effects that explain how the customer is experiencing the quality of a product (Sörqvist, 2000, p 35). Firstly, *the assimilation effect* implies that the judgment will be based upon the customer expectations. This means that the judgment will not differ from the strong original expectation, regardless of the product quality. Secondly, *the contrast effect* is the opposite of the assimilation effect. The product quality becomes truly important and will enhance the customer's positive or negative future expectations. The contrast effect will be dominating when the outcome is truly important for the customer, while the assimilation effect dominates when the outcome is hard to measure and confirm (Sörqvist, 2000, p 35-36).

3.1.3 Total Quality Management

TQM can be stated as *a constant endeavor to fulfill and preferably exceed customer needs and expectations to the lowest cost by continuous improvement work, to which all involved are committed, focusing on the processes in the organization.* The definition focuses on active preventions and changes rather than inspections and control (Bergman & Klevsjö, 2010, p 36-37). Oakland (2004, p 26) describes the concept as a combination of *communication channels, organizational culture* and *top management commitment*. In addition, Oakland includes four other dimensions to complete the TQM model, presented in Figure 3-5 (Oakland, 2004, p 36).

- **Planning** – How to develop and set up policies, strategies and resources to establish quality in an organization.
- **Performance** – Construct a measurement system that reflects the strategies and policies, monitoring the performance of the organization and perform audits, self-assessments and reviews.
- **Processes** – Understand, manage, redesign and continuously improve the processes of an organization, combining them into a QMS.
- **People** – To manage the human capital based upon teamwork, communication and organizational culture and learning.

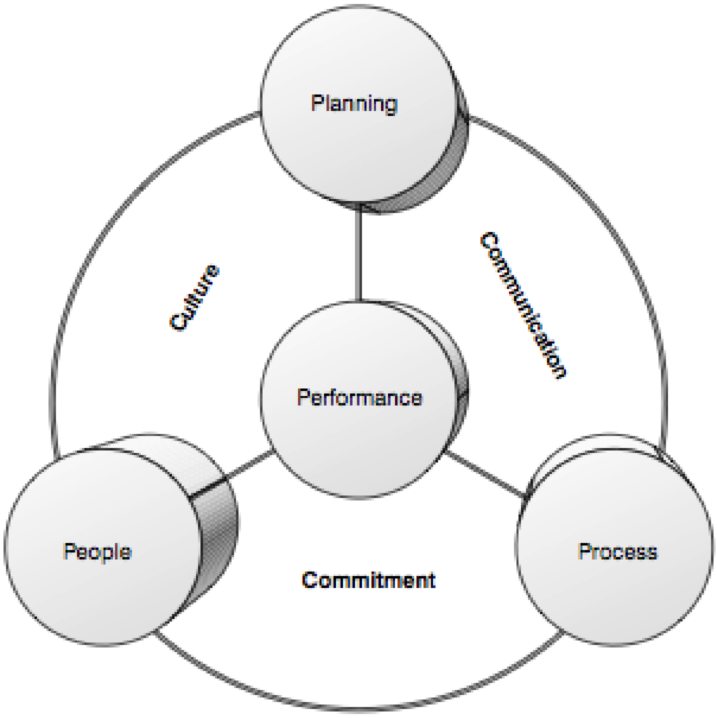


Figure 3-5: The TQM model described by Oakland (2004, p 36).

Bergman & Klevsjö (2010, p 37-46) states that the cornerstones of TQM should be based upon six interrelated main principles supported by different tools and methodologies.

- **Committed leadership** is essential since the art of top management commitment towards quality issues will reflect how the organization handles those questions.
- **To focus on customers** means knowing the customer needs, requirements and expectations in order to fulfill and hopefully exceed them. This implies focusing on both internal and external customers.
- **Basing the decisions on facts** signifies to get systematic information about customers, suppliers and in-house processes in order not to let management decisions be based on random circumstances. Improvement tools and management tools can be of great use to visualize numerical and oral information.
- **To focus on processes** implies looking at data over time and not to base decisions on single occurring events. The data should show how different activities are linked as well as their performance.
- **Continuous improvements** are necessary in order to be globally competitive. In order to increase quality and customer satisfaction, it is essential to improve processes, products and methodologies. The mental picture should be that everything can be done in a better way.
- **To let everybody be committed** aims to communicate a positive work climate, giving people a chance to perform better and improve the work situation. This implies delegating responsibility and decreasing inspection and control.

Within the TQM concept, Munch (2009, p 8) explains the importance of a quality department based upon five principles:

- The company management is responsible for quality.
- The company management can not delegate the responsibility for quality.
- The quality department is not responsible for ensuring quality, senior management must take actions.
- The quality department is only responsible for reporting quality performance; it is up to senior management to act.
- Quality management encompasses the entire company, not only certain departments.

Naguib (1993, p 64) stresses the importance of education and training when implementing TQM in an organization in order to change the organizational culture, creating a common understanding for the quality concepts and the quality policy and goals.

3.1.4 Lean and its concepts

Liker has developed the 14 principles for the Toyota Production System, claiming that they can be divided into four main areas. The areas are illustrated in Figure 3-6.

- **Long-term thinking** – The entire company must emphasize the focus of always creating a higher value for the customer and the society. To execute this task, the organization must be flexible as well as learn and improve continuously (Liker, 2009, p 16). This implies having a longer strategy perspective that eliminates short-term based decisions. The company must be responsible and evaluate processes regarding the addition of customer value (Liker, 2009, p 61).
- **Right process gives the right result** – The company needs to have a process orientation and focus on improving process flows (Liker, 2009, p 16). The company must assure that the processes create value and that the process flows are communicated within the organization, enabling visualization and elimination of problems. It is also essential to minimize buffers and level the workload as well as to encourage a culture where issues are solved directly in order to increase quality (Liker, 2009, p 61-62).
- **Add value to the organization by improving staff and collaborators** – The organization must provide tools that support employees and collaborators to improve and develop their skills, and also motivate them through participation to actively solve problems (Liker, 2009, p 17). The company must also assure that managers are committed to the philosophy and highlight the importance of team work (Liker, 2009, p 65).
- **Always striving to find root-causes to problems in order to drive organizational learning** – To find root-causes to quality problems and eliminate them is essential within the Toyota Production system. To analyze and communicate the conclusions of improvement projects as well as standardize best practice methods are truly important (Liker, 2009, p 17). Solving issues at its source and making sure that all alternatives are taken into consideration equals a learning organization, which continuously reflects and improves its work methods and capabilities (Liker, 2009, p 66).

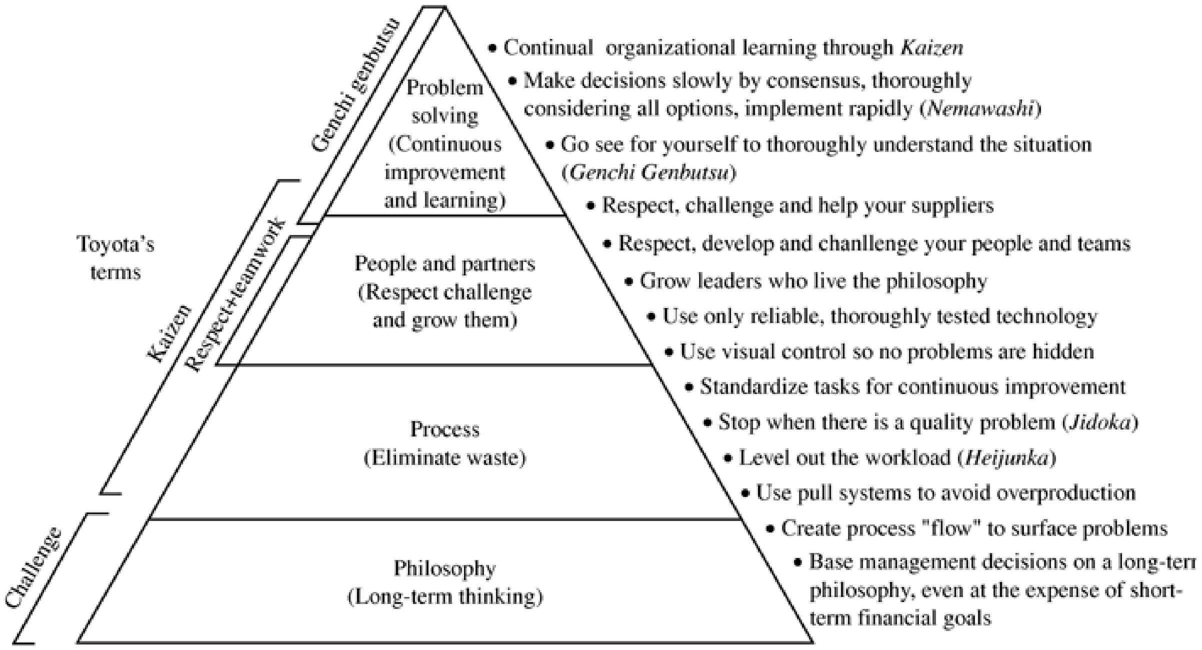
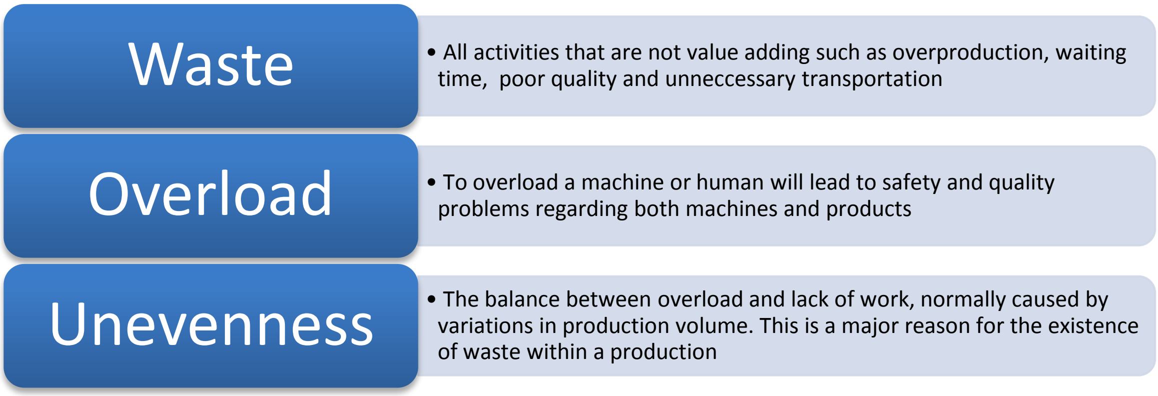


Figure 3-6: "4P"-model for the Toyota Way (Liker, 2009, p 24).

Continuous flows are essential for Lean as a concept as well as for Lean manufacturing. Within a certain production flow it is possible to find opportunities and reduce waste (Liker, 2009, p 125). When a company introduces Lean, reduction of waste tends to be the first action. However, waste is only one factor out of three that needs to be eliminated if Lean is to work properly (Liker, 2009, p 146-147). These are explained in Figure 3-7.



Waste	• All activities that are not value adding such as overproduction, waiting time, poor quality and unneccessary transportation
Overload	• To overload a machine or human will lead to safety and quality problems regarding both machines and products
Unevenness	• The balance between overload and lack of work, normally caused by variations in production volume. This is a major reason for the existence of waste within a production

Figure 3-7: The three eliminations within Lean (Möller & Sahleström, 2011).

Also, production flows have other important advantages (Liker, 2009, p 125-127):

- When working within a production flow, it is easier to build-in quality. Each operator is responsible for the quality at his work station, ensuring that quality issues and problems are revealed quickly by detecting them at as many work stations as possible.
- Production flows increase the productivity, since non-value adding time and work are detected and eliminated.

- Production flows generate true flexibility due to decreased lead time, enabling the organization to respond faster to fluctuation in customer demands.
- Production flows lower inventory cost and inventory risk when reducing buffers and work-in-progress.

3.1.4.1 Make-to-order within the Lean concept

The make-to-order (MTO) concept is further explained in chapter 3.3.1. According to Mike Rother at Lean Management Institute "*is make-to-order with a very high variety and custom-product situations often mistakenly considered unsuitable for continuous flow processing and load leveling, since the work content involved in making each different product type varies too much"*. Benefits from continuous flows can be achieved in MTO processes, by carefully regulating the work quantity and maintaining a first in, first out flow throughout all processes. The combination of the following three methods work as guidance, giving a more predictable flow that quickly highlights flow-interrupting abnormalities (Rother, p 1-2).

- Inventory should be handled as first in, first out or sequential-pull queues between processes, especially ahead of bottlenecks. A smaller first in, first out lane will result in less work on the shop floor and a shortage of lead-time (Rother, p 1).
- Release work based on a standard time increment or "pitch". Do this by determining the bottleneck operation in the critical path of your MTO process. Then break down orders into equal time increments of work based on the bottleneck capacity (Rother, p 1).
- Build ahead when you need to fill slow gaps in order to reduce volume fluctuations (Rother, p 1).

3.1.5 Six Sigma and its concepts

The Six Sigma concept is used to continuously improve certain processes or products within a business, based upon facts and analytical problem solving capabilities (Sörqvist & Höglund, 2007, p 9). Six Sigma consists of three principal components and has five areas of focus. The first component is **the result-oriented leadership**, meaning that top management must be involved and committed, having high ambitions and clear goals as well as strategies for how to execute activities and perform follow-ups (Sörqvist & Höglund, 2007, p 32-33). The second component is **infrastructure and competences**, implying that a project organization must be implemented to execute improvement activities with a project approach. The organization consists of clear roles and responsibilities, possesses accurate resources and training programs in order to execute their tasks (Sörqvist & Höglund, 2007, p 34-35). The third and final component is **the problem solving methodology**. The entire organization should have the identical systematic problem solving approach, based upon facts combined with powerful improvements tools.

In combination with the three principal components, the five areas of focus are presented below and in Figure 3-8 (Sörqvist & Höglund, 2007, p 27-30).

- ***Focus on variations***

One main cause of poor quality is that the same activity is not executed identically each time. Six Sigma aims at measuring the critical performances for each process in order to decrease the variation of the final result. With a low variation, the final result is easier to improve.

- ***Focus on customers***

When choosing which process to improve, it is essential to improve the factor that has the biggest influence on customer satisfaction and to consider which customers that will be affected.

- ***Focus on processes***

When a problem is detected, the source is often originated from previous processes. In order to solve and eliminate problems from a holistic view, both process perspective and process knowledge are fundamental.

- ***Focus on chronic problems***

Chronic problems are frequently occurring, being so common that they are considered as part of the process. Eliminating chronic problems leads to a breakthrough, showing the true potential of the improved process.

- ***Focus on results***

The critical success factor for Six Sigma is to visualize improvements and obtain results. Six Sigma is result oriented, and the success should be measured in increased customer satisfaction and decreased costs.

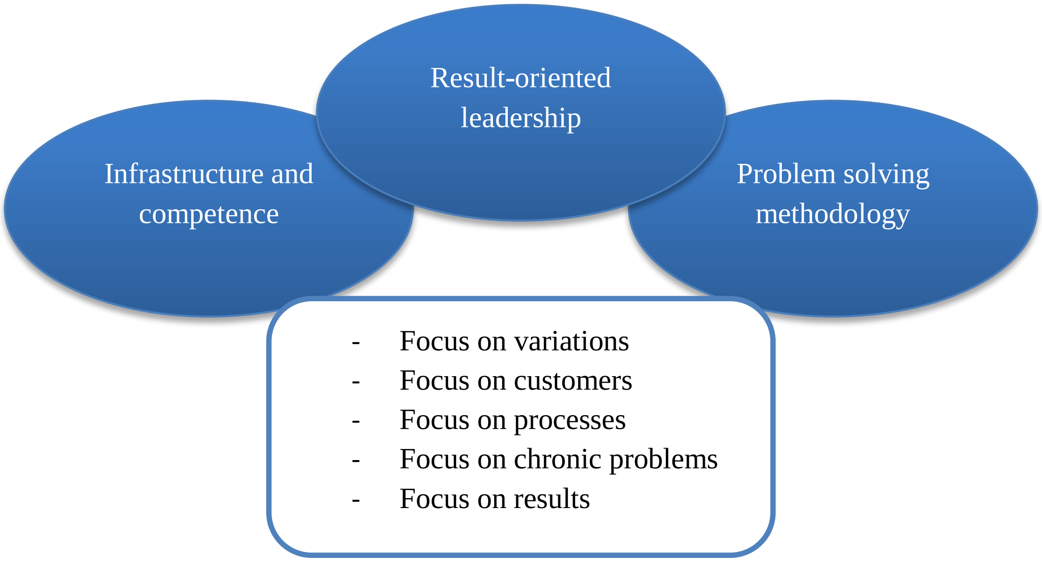
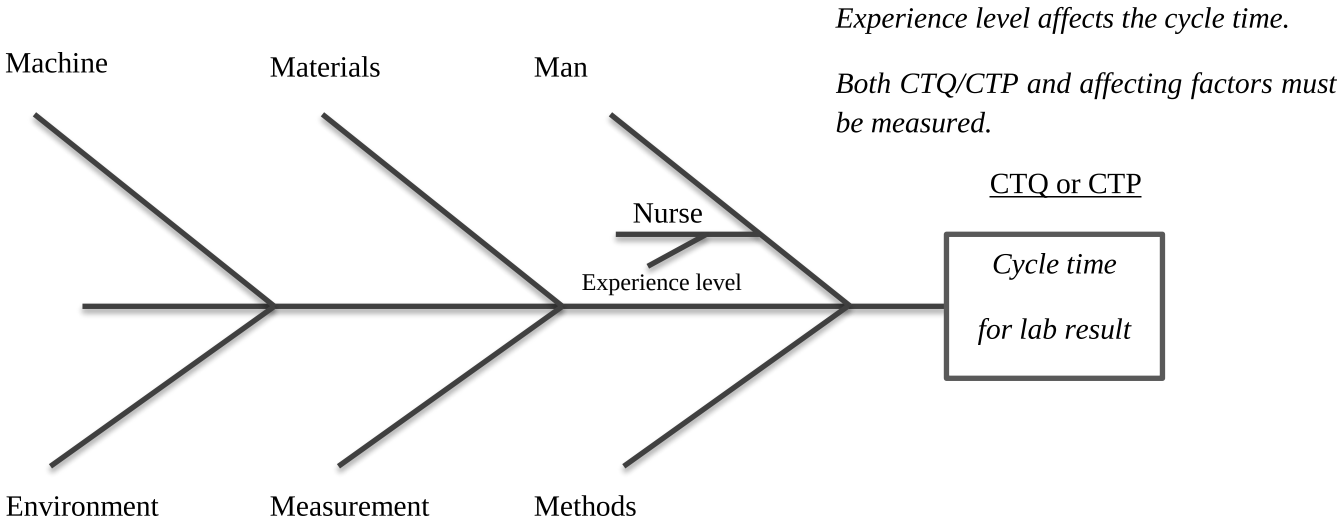


Figure 3-8: The three components and five areas of focus of Six Sigma (Möller & Sahleström, 2011).

A systematic work method is required to improve problem solving efficiency and reveal root-causes. In addition, an organization must implement a standardized and well-functioning approach to develop departments and functions (Sörqvist & Höglund, 2007, p 72). The DMAIC-model is a problem solving approach within the Six Sigma framework, representing the five phases described below:

- **Define** – A good understanding of the problem is necessary in order to obtain better results. To state a clear problem formulation and identify the project potential, its customers and their requirements eliminate obscurity and speculations (Sörqvist & Höglund, 2007, p 74-76). To identify the voice of the customer (VOC), critical customer requirements (CCR) and critical to quality (CTQ) parameters are of great importance in order to translate customer requirements into applicable measures. The VOC reflects the core of the problem, revealing the customer needs. The VOC is then translated into CCR, explaining what the customer considers important and which tolerances that can be accepted. The CCR are typically at a higher level, and are therefore translated into CTQ parameters, measuring the output of a certain process (McCarty, Daniels, Bremer & Gupta, 2005, p 348-350).

- **Measure** – Improvements must be based upon facts. The measure phase should include determining of needed data, important goals and requirements, tests and measuring methods as well as the execution of measurements (Sörqvist & Höglund, 2007, p 79-81). Since the CTQ and critical to processes (CTP) parameters have been stated in the *define phase*, the factors that affect CTQ and CTP must be determined by constructing a cause and effect diagram, where factors to each CTQ or CTP are brainstormed and defined. One example is shown in Figure 3-9. With this improvement tool, both factors and process output have been stated, and the final step is to determine how to measure these variables (McCarty, Daniels, Bremer & Gupta, 2005, p 365-367).



Experience level affects the cycle time.

Both CTQ/CTP and affecting factors must be measured.

Figure 3-9: Example of cause and effect diagram (McCarty, Daniels, Bremer & Gupta, 2005, p 367).

- **Analyze** – When analyzing data, the understanding of the problem will increase. Analysis of flows and variations are performed by using problem solving tools (Sörqvist & Höglund, 2007, p 82-84). The key delivery of this phase is validated root-causes. The chosen problem solving tools are based on the type of collected data, and both graphical tools and numerical analysis should be represented (McCarty, Daniels, Bremer & Gupta, 2005, p 393).

- **Improve** – When having identified the root-causes, solutions must be provided and implemented. The process consists of identifying suitable solutions, to test and verify the most promising ones, encourage coworkers to change processes and behaviors as well as to monitor the results (Sörqvist & Höglund, 2007, p 88-90). The deliverables from the improve phase are proposed solutions, cost and benefit analysis, an implementation plan and a final presentation for concerned managers. A

FMEA can be executed before implementing the process changes (McCarty, Daniels, Bremer & Gupta, 2005, p 429, p 446).

- **Control** – When the problems are eliminated, it is essential to visualize and communicate the obtained results. It is important to determine the risk for issues to reoccur as well as to establish preventive work methods. Also, constructing process control systems as well as performing follow-ups is part of the final phase in DMAIC (Sörqvist & Höglund, 2007, p 92-93). The deliverables of the control phase are successful solutions and a process control plan (McCarty, Daniels, Bremer & Gupta, 2005, p 457).

Six Sigma as best practice is more than a set of metrics and metric-based problem solving and process improving tools. At its highest level, Six Sigma has been developed as a practical management system for continuous business improvements that encompasses both the metrics and the methodology (McCarty, Daniels, Bremer & Gupta, 2005, p 6-7). Organizations can choose to use Six Sigma or Lean, but should not view the choice as permanent. Organizations must draw on the strength of each concept, since the two have their own benefits (McCarty, Daniels, Bremer & Gupta, 2005, p 154-155).

3.1.6 Quality methods & tools

3.1.6.1 Quality Management System

A QMS is by ISO-9000 defined as *a management system to direct and control an organization with regard to quality*. Also, a QMS should be considered as a tool for controlling and improving the quality of a company's processes and products and must therefore be well documented (Bergman & Klevsjö, 2010, p 484). A QMS should contain all activities that affect quality, as well as describing the internal relations between them (Sandholm, 2008, p 312).

The leading QMS is the ISO-9000 family. The ISO-9000 family consists of three standards that guide the structure of a QMS (Sandholm, 2008, p 313):

- **ISO-9000** – Principle and terminology.
- **ISO-9001** – Demands and requirements.
- **ISO-9004** – Guidance to business improvement.

ISO-9000:2008 is based upon eight management principles that should be used as a framework to guide an organization towards future improvements (www.iso.org, 110927).

- **Customer focus** – Current and future customer needs should be understood and customer requirements should be met or exceeded.
- **Leadership** – Leaders should create and maintain an internal environment, in which people can be fully involved in achieving the organization's objectives.
- **Involvement of people** – People are the essence of an organization and their involvement enables their capabilities to be used for the organization's benefit.
- **Process approach** – Desired results are achieved more efficiently when activities and resources are managed from a process perspective.
- **System approach to management** – Managing interrelated processes as a system contributes to the organization's effectiveness and efficiency.

- **Continual improvements** – Continual improvements of the organization's overall performance should be a permanent objective of the organization.
- **Factual approach to decision making** – Effective decisions are based on analysis of data and information.
- **Mutually beneficial supplier relationships** – An organization and its suppliers are inter-dependent, and a mutual beneficial relationship enhances the ability for both parties to create value.

ISO-9001:2008 includes demands and requirements of a QMS, serving as a standard when certificating organizations according to ISO-9000. The standard requires a process perspective, where process control should successfully transform customer needs to customer satisfaction (Sandholm, 2008, p 315). The standard clarifies demands regarding improvements of the QMS, management responsibility, management of organizational resources, realization of products and services as well as how to measure, analyze and improve (Sandholm, 2008, p 315-316). The interrelations between these five main areas and the transformation from customer requirements to customer satisfaction are illustrated in Figure 3-10. Four of the main areas are explained below (Bergman & Klevsjö, 2010, p 493-496).

- **Management responsibility** includes management commitment to construct and improve the QMS, ensuring maintained customers focus as well as setting quality policies and goals.
- Cornerstones of **resource management** are to establish and provide needed resources for the organization, ensuring development of human capital and company infrastructure as well as maintaining a healthy work environment.
- **Product realization** describes how to perform product development according to customer needs and requirements, how to control and execute purchasing and production processes as well as how to state measurement system requirements.
- **Measurements, analysis and improvements** imply that an organization should implement and continuously improve a measurement system in order to measure and monitor both external customer satisfaction and performances of internal processes.

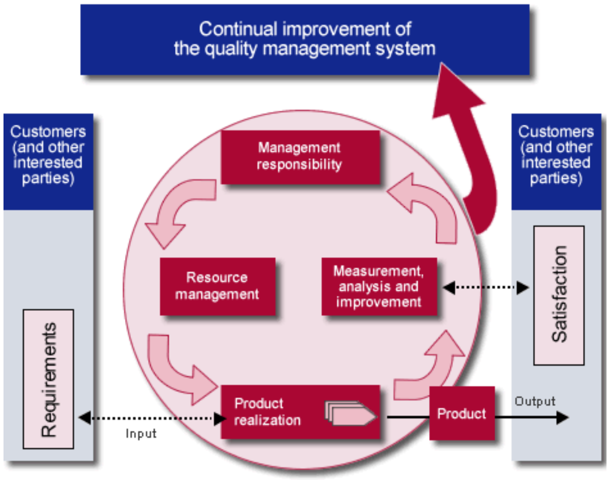


Figure 3-10: ISO-9001 requirements and principles (iso9001consultancy.blogspot.com).

ISO-9001 demands a certain level of documentation, compiled in a quality handbook serving as a coordination tool for quality operations. Quality policy, quality goals, organization, systems and methods should be documented. ISO-9001 contains a handbook disposition, helping organizations to link the demands with the content of the quality handbook. The documentation should be at three levels according to the standard (Sandholm, 2008, p 319-320):

- **Level 1** – A holistic summary that covers a specific main area, e.g. management responsibility. This level is to be used when presenting an overview, e.g. during audits.
- **Level 2** – Implies a detailed description of a specific main area, including work methods and routines that usually affect several departments.
- **Level 3** – Detailed instructions of how a certain task within a specific main area is to be executed. These instructions are destined for individual workers and should not be included in the quality handbook.

ISO-9004:2008 serves as guidance to clarify the demands stated in ISO-9001. However, the demand interpretations in the ISO-9004 are not officially approved, and should therefore only serve as direction (Sandholm, 2008, p 317).

Bergman & Klevsjö (2010, p 491) stress that when implementing a QMS, an organization must go through the following actions according to the ISO-9001 standard:

1. Identify all processes needed for the QMS.
2. Determine the interaction between those processes.
3. Ensure that operation and control of those processes are effective.
4. Ensure that required resources and information needed to execute those processes are provided.
5. Measure, monitor and analyze those processes in order to obtain and continuously improve given objectives.

Hoyle (2008, p 81) remarks that the implementation itself will not lead to improved quality. The most common mistake by organizations is to go through the following ritual; document what one does, do what one documents, and then prove it. This approach is equal to be medicated, but continuing the lifestyle that prompt the medication. In order to achieve, sustain and improve quality, different approaches such as quality assurance, system development, documentation, measurements and external audits are required. The point of view towards those approaches will determine the success of a QMS (Hoyle, 2005, p 91). For management, a system approach is of true importance in order to develop a process-based QMS. It is essential to view the company as a system of processes and manage their interactions to produce desired outcome (Hoyle, 2005, p 111-112). Therefore, having a process approach is also desirable. Transformation from a functional to a process perspective, introducing a system of processes as well as their interactions and directions is a part of this approach (Hoyle, 2005, p 137). Finally, a behavioral approach focuses on the interaction between people, increasing motivation to achieve given objectives (Hoyle, 2005, p 173). These three approaches are essential to obtain the full potential of a QMS.

3.1.6.2 FMEA

Failure mode and effect analysis (FMEA) is a systematic approach to investigate the reliability, risks and potential sources to failure of a product or process. The approach implies reviews of functions, failure modes, failure causes and failure consequences of the investigated object (Bergman & Klevsjö, 2010, p

159). The product or process is analyzed in detail, and risks regarding failure appearance, failure effect and the possibility of detection are estimated (Ståhl, 2011, p 309).

A system FMEA is performed when receiving product requirements from customer. A construction FMEA is performed when the product construction is in its final phase, however changes are still permitted. A production FMEA is performed to increase the knowledge of the production process and its sensitivity towards interferences (www.fmeainfocenter.com, 111019).

A FMEA should be performed within a group of individuals representing different functions, although having good knowledge regarding the investigated object. The individual mix is important in order to enlighten different point of views. The composition of the group is a key factor to success and the procedure is generally based upon brainstorming (Sörqvist, 2004, p 494-495). The work process consists of the following 9 steps (www.fmeainfocenter.com, 111019):

1. Identify all different kinds of possible failures.
2. Identify the effects of a certain failure.
3. Identify the cause of the failure.
4. Identify the present and needed control in order to detect the failure.
5. Estimate the probability that the failure will occur.
6. Estimate the effect of the failure.
7. Estimate the possibility to detect the failure.
8. Calculate the risk potential.
9. Identify suitable interventions for the failure.

When estimating the three risk factors in step 5-7 above, pre-defined criteria and rankings must be established, demonstrated by the following example (www.d5q.se, 111020):

Probability of failure	Ranking
Unlikely to occur	1
Quite unlikely to occur (No reclamations)	2
Process reliability is within the tolerances	3-4
Small probability to occur (Close to not fulfilling requirements)	5-6
Large probability to occur (Not fulfilling requirements)	7-8
Very large probability	9-10

Failure effect	Ranking
No impact on product or process	1
Small impact on product or process	2
Risk for product or process failure	4-6
Production is no longer possible	8-9
Risk for personal danger or law violation	10

Possibility of detection	Ranking
Spotted by the operator	1-2
Spotted at the machine/refining	3-4
Spotted in the production	5-6
Spotted at the final inspection	7-8
Spotted by the end customer	9-10

3.1.6.3 Five whys, part of the Toyota Problem Solving Method

The five whys methodology is one of the most important improvement tools within the Toyota Production System and Lean. It is used as part of the practical problem solving process of Toyota. The basic idea is to frame and understand an issue, and then investigate the root-causes beyond the source of the problem by using the interrogative "why" five times. However, in order to eliminate the true root-cause, it is not enough to only identify the source. In detail, the five why methodology consists of seven steps, described below. Firstly, a proper understanding of the situation needs to be in place (1-3). Secondly, an investigation in order to identify the root-causes of the problem should be executed (4). Finally, actions and interventions need to be introduced. These must be evaluated and standardized in order to become best practice in the future (5-7) (Liker, 2009, p 300, 303-304).

1. A brief comprehension of the problem.
2. Clarify the problem with help of e.g. Pareto analysis.
3. Localize the point of cause (POC), also referred to as the source.
4. Perform root-cause analysis by using the five whys.
5. Introduce actions and interventions.
6. Evaluation.
7. Standardization.

3.1.6.4 Continuous improvements

The concept of continuous improvements is represented within several quality models. Kaizen is a method within Lean where continuous improvements should be integrated in the daily work and have full attention and support from top management (Sörqvist, 2004, p 42). Six Sigma highlights the importance of top management supporting and leading improvement projects (Sörqvist, 2004, p 51). Continuous improvements are also emphasized in the later versions of ISO 9000, claiming that an organization should have a process that manages quality improvement initiatives (Sörqvist, 2004, p 56).

Improvements can be performed with different focuses. With a *customer focus*, improvement actions target activities that will increase customer value and satisfaction. With a *process focus*, the aim of the improvements is to increase the company efficiency. These two focus areas will strongly reveal if the improvements are initiated from a *product VS operational point of view*. Improvement work can also be considered having a *revenue VS cost focus* (Sörqvist, 2004, p 73).

Oakland (2001, p 228) asserts that continuous improvements is the most powerful concept to guide management. The first cornerstone is customer focus, striving towards serving the customer better. The second implies measuring, monitoring and understanding processes in order to prevent failures. The commitment of the employees lies as the third cornerstone, which is to convince everyone of their role in the quality improvement development (Oakland, 2001, p 228-230). Oakland (2001, p 239-240) also highlights the importance of a successful introduction to continuous improvements. Besides getting full support from top management and nominate a motivated project leader, the improvement development should start with a smaller pilot project. When the outcome is considered successful, it can be spread within the entire organization. The improvement process must then be documented to ensure future project success.

A successful improvement work tends to be hard to execute. According to Sörqvist (2004, p 138-140), the 10 most important success factors within continuous improvements are the following:

1. True commitment from management and coworkers.
2. A well developed and suited improvement organization.
3. The right people to manage, control and support the improvement work.
4. Having result and customer focus as well as setting high striving improvement goals.
5. Choose feasible and appropriate projects that eliminate chronic problems.
6. Powerful methods, logic work process and fact-based problem solving.
7. Knowledge and continuous education to master the actions needed.
8. Follow up and present feed-back in order to verify that objectives are obtained.
9. Adjust methods and concepts to the organization's business culture and situation.
10. Integrate the already existing methods, within the organization, with appropriate supplements.

The ISO-9000 standard requires an organization *to continually improve the effectiveness of the quality management system through the use of quality policy, quality objectives, audit results, analysis of data, corrective and preventive actions and management review*. The improvements through the use of ISO-9000 include ten key areas. Firstly, the organization must establish a QMS and improve its effectiveness. Secondly, necessary actions to improve the defined processes in the QMS must be established. The other key areas are summarized as: Top management must show and provide evidence of their commitment to process improvements, which must also be reflected in the quality policy. The output of the management review should consist of actions and decisions, of how to improve the QMS and products, so that customer requirements can be fulfilled. The organization must provide resources as well as to measure, analyze, monitor and control the QMS in order to improve its effectiveness based upon reviews, data collections, policies, goals and objectives. In summary, establishment of a QMS acts as a foundation for the remaining nine key areas, where focus lies on the total process or specific parts of the improvement work (Hoyle, 2009, p 670).

Continuous improvements are also a question of mindset. Bellgran & Yamamoto (2010, p 126-127) claims that provoking employees to experience the need of improvements is the key to improvement success. Each improvement starts with a need, and improvements without needs tend to be unsuccessful. Bellgran & Yamamoto (2010, p 127) summarize and describe the insight as following:

"Create a situation where people have no choice (or little choice) but to feel the need of improvement. The situation is such that it brings different wastes and problems up to surface. Through letting people solving the wastes and problems one by one, the performance of the operation as well as the capability of individual and organizational learning are improved"

3.1.7 Cost of poor quality

There are various numbers of COPQ definitions. In order to capture the big variety of quality definitions, the COPQ must be explained in a broader sense. COPQ can be defined as *the total losses that occur when products or processes of a company are not absolute*. Losses imply the total effect that poor quality has on revenues, costs and resources. It is recommended to begin with the broader definition, and later delimit towards specific areas (Sörqvist, 2008, p 31-32).

The COPQ concept has different scope of use. Firstly, the approach towards poor quality will change when COPQ is quantified into numbers, giving a substantial understanding of the potentials of quality improvements that most people can refer to. Secondly, quantifying COPQ will demonstrate improvement potentials, giving the opportunity to prioritize which issue that should be addressed. The third scope of use is to be able to follow-up and measure quality interventions that have been realized (Sörqvist, 2008, p 32-33).

COPQ can be summarized in three categories. **Internal costs** refer to losses caused by deviations of required level of quality detected before delivery to external customers (Sörqvist, 2008, p 37). This implies rejections, re-work, re-controlling and other administrative tasks that need to be repeated (Sandholm, 2008, p 211). **External costs** are defined as losses caused by deviations of required level of quality discovered after delivery to external customers (Sörqvist, 2008, p 37). It includes cost of reclamations, guaranties, discounts, claims and loss of goodwill (Sandholm, 2005, p 212). Thirdly, **control costs** are defined as costs caused by controlling quality at each process step (Sörqvist, 2008, p 36). Control of incoming goods, manufacturing control, final control, quality evaluation and special control belong to this category (Sandholm, 2005, p 211). According to Sörqvist (2008, p 34-35), prevention costs should no longer be viewed as part of COPQ, but should be seen as investment costs made to increase the level of quality, thereby lowering the cost of failures.

Cost factors within an organization can either be measurable or hidden. The COPQ must therefore be categorized in the following five levels (Sörqvist, 2008, p 38-42):

- ***Traditional COPQ***

These are the most obvious costs that are often measured within production, capturing rejections, re-work and claims. It is important to not only consider traditional COPQ when prioritizing quality improvement projects, since the risk of sub-optimization is high due to lack of knowledge of hidden costs.

- ***Hidden COPQ***

Hidden COPQ represents the costs that directly strike the company and its business, however are hidden in the accounting system. Wages, material and production expenditure are the most common ones. This level signifies the chronic problems within an organization or production; problems that occur regularly but are never registered.

- ***Lost revenues***

Revenues that are missed out when delivering non-quality requirement fulfilled products to markets or customers. This implies loss of goodwill and increases the risk of losing customers.

- ***Costs for the customer***

This implies costs that strike a customer due to poor quality from its suppliers. These costs are strongly connected to the cost of lost revenues, since they are causing the loss of goodwill. It is not appropriate for participants within the value chain of today to sub-optimize their COPQ without taking their suppliers and customers into consideration.

- ***Costs for the society***

These costs are defined as the losses within the society caused by poor quality of an organization's products or services. Two examples are environmental costs and socioeconomic costs in terms of unemployment and lack of tax income caused by non-profitable business cooperation. Organizations should be aware of these costs, since the effects in the longer perspective might imply higher taxes and duties when national economy declines.

3.2 Manufacturing and manufacturing cost model

3.2.1 Types of manufacturing

All types of industrial manufacturing are characterized as refinement of material, leading to a product. A classification of manufacturing systems is often made based on batch sizes and the amount of manufactured products. The divisions are commonly the following (Ståhl, 2011, p 28-29):

- **Single-unit manufacturing systems** are characterized as producing small production volumes to specific customer orders with great variation in product construction, which requires flexible manufacturing equipment.
- **Batch manufacturing systems** are characterized as producing medium-sized batches of one product, often as make-to-stock, further explained in chapter 3.3.1.
- **Mass production manufacturing systems** are characterized as producing one single product with high production rate.

3.2.2 Types of layouts

A manufacturing system can be divided into three different types of layouts. These are usually classified according to the actual placement of the manufacturing equipment (Ståhl, 2011, p 30).

- **Project layout** – The processing is located to one place since the product is usually large, heavy and difficult to move. The layout is commonly used for long lead times and small batches.
- **Function oriented layout** – The machines are arranged according to their functions, placing machines with the same function in the same area. This usually results in more complex material handling and longer internal transports. However, it renders the possibility of producing different products, since the sequences can be varied.
- **Line production** – The machines are arranged in the processing order for a certain product, thus giving a clear production flow and a higher production rate. The layout requires larger investments in machines and is suitable for large batches and mass production.

3.2.3 Manufacturing parameters

The capacity, manufacturing cost and the competitiveness of a manufacturing system are to a great extent controlled by the production time per part. Within a manufacturing system, the production time per part consists of the nominal cycle time, t_0, plus the altogether added time from *downtime*, *rejections*, *production rate* and *setup time* (Ståhl, 2011, p 67).

The nominal cycle time, t_0, is the ideal time it takes for a part to be processed in a machine or equipment. It is described as the sum of machine time, t_m, handling time, t_h, tool changing time, t_{vb}, and wasted time, t_{no} (Ståhl, 2011, p 67).

$$t_0 = t_m + t_h + t_{vb} + t_{no}$$ ***Equation 3-1***

The machine time is built up from other operation sequences and is described as the sum of operational processing time, t_f, internal machine transporting time, t_{tr}, time of support processes, t_{sp} and time to ensure quality, t_{kvs} (Ståhl, 2011, p 68).

$$t_m = t_f + t_{tr} + t_{sp} + t_{kvs}$$ ***Equation 3-2***

The production time per part, t_p, is longer than nominal cycle time since it takes the downtime per part, t_s, into consideration. The sum of the nominal cycle time and the downtime per part equals the production time per part. The percentage of downtime is described as the **downtime ratio**, $\mathbf{q_S}$ (Ståhl, 2011, p 68-69).

$$q_s = \frac{t_s}{t_p} = \frac{t_p - t_0}{t_p} \qquad \textit{Equation 3-3}$$

In order to compensate for quality losses within the manufacturing system a certain amount of parts, N, have to be produced. This value will be the sum of the nominal value of correct parts or nominal batch size, N_0, and the amount of rejected parts, N_Q. The percentage of rejections is described with the **rejection rate,** $\mathbf{q_Q}$ (Ståhl, 2011, p 69).

$$q_Q = \frac{N_Q}{N} = \frac{N - N_0}{N} \qquad \textit{Equation 3-4}$$

When the nominal cycle time, t_o, has to be increased to the true cycle time, t_{ov}, this implies a production rate loss due to lengthening of cycles. The reason for the rate losses might be to avoid unplanned downtime. The **production rate loss**, $\mathbf{q_P}$, is defined as the percentage of the increased cycle time (Ståhl, 2011, p 69).

$$q_P = \frac{t_{0v} - t_0}{t_{0v}} = 1 - \frac{t_0}{t_{0v}} \qquad \textit{Equation 3-5}$$

In order to change the production from part A to part B, a production **setup time**, $\mathbf{T_{SU}}$, is required. When the setup time is longer than the nominal setup time, T_{SU0}, the downtime rate, q_{Ssu}, describes the setup losses (Ståhl, 2011, p 70).

$$T_{SU} = \frac{T_{SU0}}{1 - q_{SU}} \qquad \textit{Equation 3-6}$$

Another parameter that affects the production cost is the overcapacity of machine equipment. This occurs when the **degree of utilization**, $\mathbf{U_{RB}}$, of the manufacturing system is less than 100 %. Overcapacity can be seen both as an asset and as a financial burden depending on the actual situation. Financially, it will be regarded as a setup time and is then described as the percentage between downtime due to free capacity, T_{SFK}, and planned production time, T_{PLAN} (Ståhl, 2011, p 99).

$$U_{RB} = \frac{T_{PLAN} - T_{SFK}}{T_{SFK}} = 1 - \frac{T_{SFK}}{T_{PLAN}} \qquad \textit{Equation 3-7}$$

If the time for overcapacity is distributed over all batches for a certain production time, T_{Pb}, the downtime due to **free capacity** per batch, $\mathbf{T_{SFKb}}$, can be calculated as following (Ståhl, 2011, p 99).

$$T_{SFKb} = \frac{1 - U_{RB}}{U_{RB}} T_{Pb} \qquad \textit{Equation 3-8}$$

Production time per batch**, t_{Pb},** is defined as (Ståhl 2011, p 70):

$$T_{Pb} = T_{SU} + \frac{t_0 N_0}{(1 - q_Q)(1 - q_S)(1 - q_P)} \qquad \textit{Equation 3-9}$$

3.2.4 Manufacturing cost model

According to Ståhl (2011, p 83-84), the basis of a cost model used for manufacturing is to describe the costs at the same level where changes and development should be done. This means that the cost model should only include variables which are of the utmost importance for the manufacturing costs, and not taking any general overhead costs into account. The following theoretical cost model uses this calculation approach and serves as a cost break down (CBD) model.

3.2.4.1 Cost break down model

The CBD model can be applied to a planning point within a production. A planning point refers to a delimited number of refinement processes, for which a nominal cycle time and a nominal lead time, for a part and batch, have been determined. A planning point can therefore constitute one single machine process or a complete production flow. The CBD model below is taken from Ståhl (2011, p 84-85) and describes the manufacturing cost per part.

$$\begin{aligned} k = {} & \frac{k_A}{N_0}\left[\frac{1}{n_{PA}}\right]_a + \frac{k_B}{N_0}\left[\frac{N_0}{(1-q_Q)(1-q_B)}\right]_b + \frac{k_{CP}}{60N_0}\left[\frac{t_0 N_0}{(1-q_Q)(1-q_P)}\right]_{c1} + \\ & \frac{k_{CS}}{60N_0}\left[\frac{t_0 N_0}{(1-q_Q)(1-q_P)}\frac{q_S}{(1-q_S)} + T_{SU} + \frac{1-U_{RB}}{U_{RB}} T_{Pb}\right]_{c2} + \\ & \frac{k_D}{60N_0}\left[\frac{t_0 N_0}{(1-q_Q)(1-q_P)(1-q_S)} + T_{SU} + \frac{1-U_{RB}}{U_{RB}} T_{Pb}\right]_d \end{aligned} \qquad \textit{Equation 3-10}$$

The equation consists of cost parameters and cost terms. Altogether, they build up the manufacturing cost. The cost parameters are described as following (Ståhl, 2011, p 83-86, 97):

- Tool cost, k_A.
- Material cost per part, k_B.
- Hourly machine production cost, k_{CP}.
- Hourly machine downtime cost, k_{CS}.
- Hourly wage cost, k_D.

The cost term for each parameter is described as following:

Cost term a describes the tool cost per part where the total tool cost is distributed over the number of batches, n_{PA}, and the batch size for which the tools have been used (Ståhl, 2011, p 97).

Cost term b describes the material cost per part where the cost for rejection rate and material wastage, $\mathbf{q_B}$, is distributed evenly over the batch size. Material wastage affects the material cost, corresponding to the percentage difference between total use of material, m_{tot}, and the quantity of material of the finished part, m_{det}. The material cost should be based on the purchase price and the warehousing costs (Ståhl, 2011, p 85-86, 96).

$$q_B = \frac{m_{tot} - m_{det}}{m_{tot}}$$ **Equation 3-11**

Cost term c1 describes the production costs during processing. The cost for production takes the rejection rate and production rate loss into consideration (Ståhl, 2011, p 85).

Cost term c2 describes the production costs during downtime. The cost for downtime, setup time and degree of utilization is also taken into consideration (Ståhl, 2011, p 85).

Cost term d describes the wage cost at all production time. The wage cost consists of wages for industrial workers with all supplements included as well as costs for locker rooms (Ståhl, 2011, p 85-86).

3.2.4.2 Machine costs

The hourly machine costs calculation, k_{cp} and k_{cs}, uses the annuity method in order to determine the yearly cost for the initial investments. For increased comparison, the expected technical lifetime of the machine is used, which generally is 2-4 times longer than the expected economic lifetime. The hourly machine cost can be built up of different costs. Besides the investment cost, the following costs connected to each machine can be included (Ståhl, 2011, p 90-91):

- Facility costs, includes heating and rental.
- Maintenance costs.
- Variable operation costs.
- Renovation costs.

3.2.5 Economically based KPI

The manufacturing-economic efficiency (TEV, TillverkningsEkonomisk Verkningsgrad) describes the relation between ideal and actual manufacturing cost. Both ideal and actual costs are calculated using the CBD model. Due to performance and degree of utilization, TEV becomes less than 1,0. TEV is used to find a distinct measured value, representing the technical production performance as a cost based KPI in order to identify improvement potentials (Ståhl, 2011, p 106-107).

$$\eta_E = \frac{k_{Ideal}(q_Q, q_S, q_P, T_{SU} \ldots\ldots = 0, U_{RB} = 1{,}0)}{k}$$ **Equation 3-12**

3.2.6 Systematic Production Analysis

A systematic production analysis (SPA) provides an essential basis for decision-making regarding changes and development within a manufacturing system. It should reflect real manufacturing conditions and provide a calculation base in order to determine the loss terms within the production performance; *rejection rate, downtime* and *production rate loss*. A tool used to perform a SPA is the production performance matrix (PPM) which thoroughly connects the controlling factors to the production result (Ståhl, 2011, p 161).

3.2.6.1 Production performance

The result of all commodity industrial production can be described in three result parameters shown in Figure 3-11, *rejection rate*, *downtime* and *production rate loss*. The balance shown between the result parameters and the production cost is applicable for almost every processing industry. It implies that a reduction of one result parameter does not necessarily mean a reduction in production cost. The increase of the other two result parameters might exceed the well thought-out cost reduction and result in a lower production performance than before (Ståhl, 2011, p 161-162).

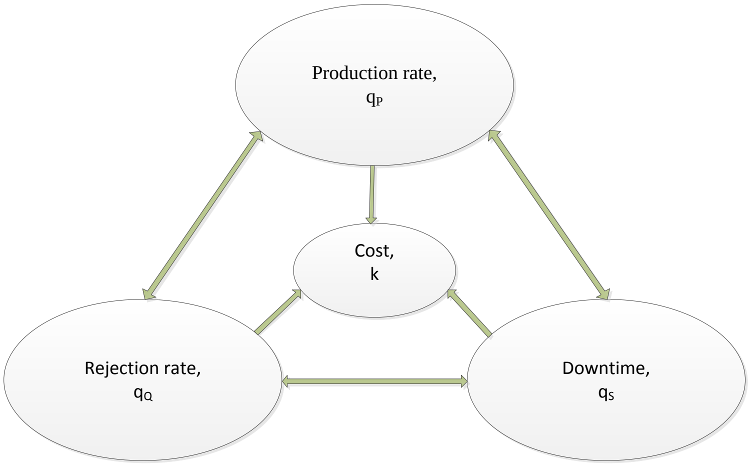


Figure 3-11: Correlation between production rate, rejection rate and downtime (Ståhl, 2011, p 162).

3.2.6.2 Production Performance Matrix

A PPM is built up by result parameters, factor groups and its factors. These are combined, forming a matrix illustrated in Figure 3-12, where the result parameters constitute the columns and the factors constitute the rows (Ståhl, 2011, p 161-162, 191).

The result parameters are divided into the following main categories and can in most cases be expressed in absolute numbers (Ståhl, 2011, p 161-162, 188, 191):

- **Quality parameters** – are described by the *rejection rate* and refer to the dimensional requirements, surface requirements and characteristic requirements.
- **Downtime parameters –** are described by the *downtime* and refer to process related occurrences.
- **Production or processing rate parameters** – usually refer to the amount of parts produced per time unit. Losses in production rate are described by the *production rate loss*.

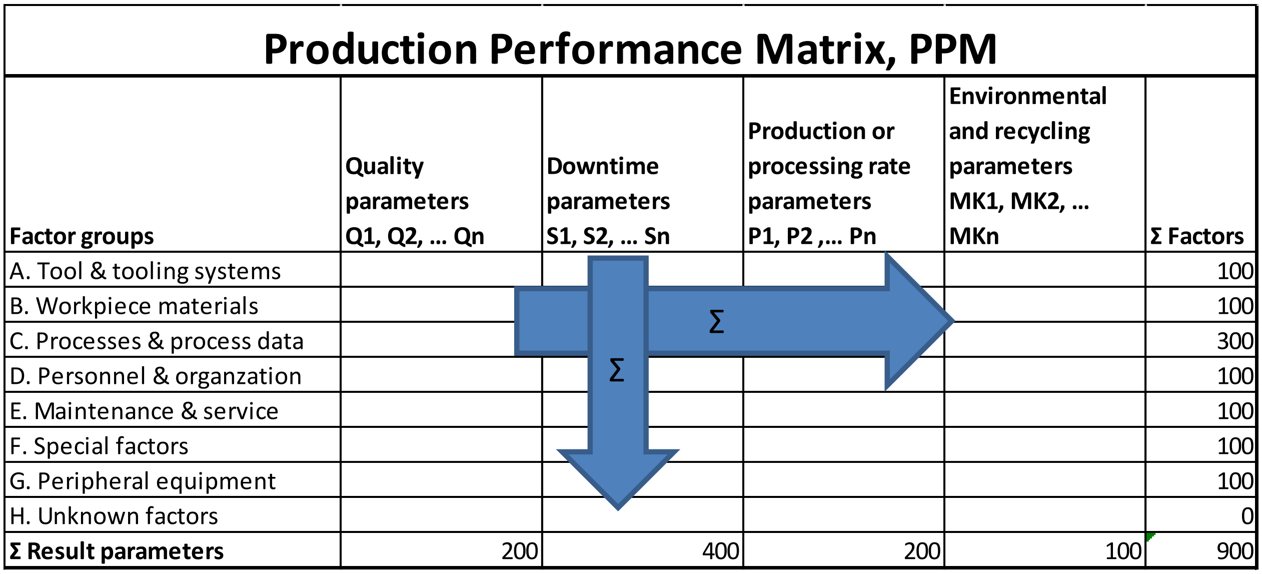
There is a fourth category of result parameter, **environmental and recycling parameters**, which takes energy usage, production wastage and recyclability into account. However, these result parameters will not be used in this master thesis.

The factor groups describe and control the influence of the production performance within a manufacturing process. Each factor group contains a various number of factors which, separately or combined, affect the production performance (Ståhl, 2011, p 188-189).

The factor groups are divided as following:

- **A. Tool & tooling systems** – Factors related to geometry, surface and material.
- **B. Workpiece materials** – Factors related to geometry, surface and material.
- **C. Processes & process data** – Factors related to equipment, process data and additive processes.
- **D. Personnel & organization** – Working conditions, instructions, handling and responsibility.
- **E. Maintenance & service** – Planned maintenance and immediate maintenance.
- **F. Special factors** – Unique behaviors for the actual process.
- **G. Peripheral equipment** – Handling equipment, conveyor belts and grippers.

Factor groups A-D can be seen as input in the production system, whereas the factor groups E-F are considered as a consequence of the current production. In order not to degrade the information quality in the mentioned factor groups, one last factor group is used, **H. Unknown factors**. This is where problems that can not be identified are registered (Ståhl, 2011, p 189).



Production Performance Matrix, PPM

Factor groups	Quality parameters Q1, Q2, … Qn	Downtime parameters S1, S2, … Sn	Production or processing rate parameters P1, P2 ,… Pn	Environmental and recycling parameters MK1, MK2, … MKn	Σ Factors
A. Tool & tooling systems					100
B. Workpiece materials					100
C. Processes & process data					300
D. Personnel & organzation					100
E. Maintenance & service					100
F. Special factors					100
G. Peripheral equipment					100
H. Unknown factors					0
Σ Result parameters	200	400	200	100	900

Figure 3-12: The contexture of the PPM (Ståhl, 2011, p 192).

3.3 Supply chain management

Supply chain management (SCM) is a vast topic that tends to get personal definitions. One might say it implies managing the supplier base, to some it involves distribution and transportation, and for another it represents the management of fixed and variable assets required for running a business. A comprehensive definition can therefore be given as stated below, with Figure 3-13 as complement (Swaminathan, 2000, p 3):

Supply Chain Management (SCM) is efficient management of the end to end process starting from the design of the product or service to the time when it has been sold, consumed and finally gotten rid of by the customer. This complete process includes product design, procurement, planning and forecasting, production, distribution, fulfillment and after-sale support.

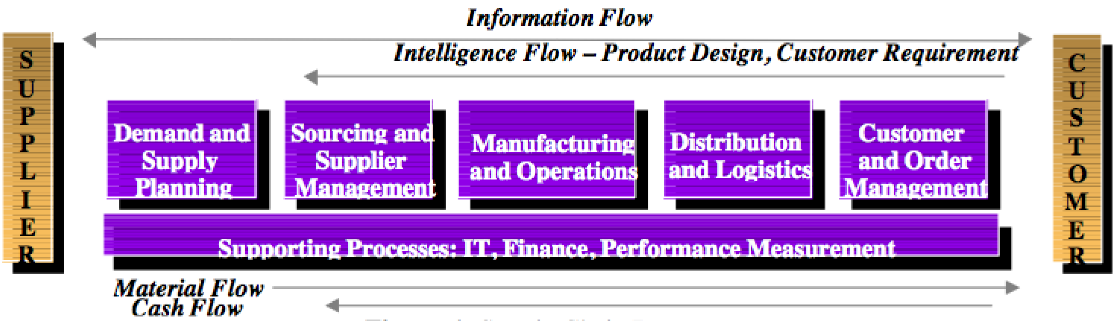


Figure 3-13: The SCM process (Swaminathan, 2000, p 4).

SCM can be divided into *configuration* and *coordination*. Configuration relates to the infrastructure on which the supply chain executes and coordination is related to the performance of the supply chain. The configuration part consists of the following topics (Swaminathan, 2000, p 4-5):

- **Supply base decisions** – Number of suppliers for each category, contract types, outsourcing or in-house decisions, standardization of procurement practice.
- **Plant location decisions** – Number and geographical locations of manufacturing facilities, capacity and distribution set-up for each plant.
- **Product portfolio decisions** – Which products and services to support throughout the supply chain, product variety, commonality across the portfolio.
- **Information support decisions** – How to standardize the supply chain resource planning system between functions and which type to use.

The coordination part consists of the following topics (Swaminathan, 2000, p 5-6):

- **Material flow decisions** – Inventory levels, inventory replenishment time, just-in-time-policies, self-controlled or vendor managed inventory (VMI).
- **Information flow decisions** – Information sharing throughout the supply chain, collaboration between supply chain participants in different situations.
- **Cash flow decisions** – Supplier payment, currency issues, costs and cost reductions.
- **Capacity decisions** – Optimize available capacity, production planning, numbers and sizes of buffers.

According to Swaminathan (2000, p 6-9), the most difficult areas to handle within SCM are the following:

- **Multiple agents** – A supply chain consists of different agents with different interests that might be contradictious.
- **Uncertainty** – The uncertainty of supply and demand affects the whole supply chain.
- **Information asymmetry** – Since a supply chain stretches through a vast number of functions within different firms, an asymmetry of information occurs. This is mainly due to different information systems between different agents as well as the unwillingness of information sharing.
- **Lead time** – Lead time within a supply chain is crucial, however some actions cannot be executed before knowing the real demand.
- **Utilization of inventory assets** – This implies the balance of having inventories at one end of the supply chain, when there is a shortage at the other.
- **Distortion of information** – Also called the bullwhip effect, meaning that inventories get amplified down the supply chain caused by a smaller demand. This is due to lack of collaboration and information sharing.
- **Customized challenges** – The challenge of providing a variety of products while decreasing costs and controlling the supply chain.

3.3.1 Make-to-order supply chain

A supply chain can be distinguished into three different categories: Make-to-stock, assemble-to-order and make-to-order (MTO), also known as build-to-order (BTO). Make-to-stock supply chains work on an anticipatory model, in which products are manufactured according to forecasts. MTO supply chains involve the highest degree of interaction with the market, since no manufacturing processes are performed before a customer order is received. Assemble-to-order supply chains result in a hybrid model, in which modulus are manufactured according to forecasts, however the end product is not assembled before a customer order arrives (Blecker & Abdelkafi, p 1).

The differences between traditional SCM (TSCM) and MTO are illustrated in Figure 3-14. In TSCM, customer requirements are satisfied from stock, while in MTO, stocks are built based on customer orders. Focus within TSCM lies on a stable production with stochastic demand while MTO emphasizes customized demand and supply chain flexibility. Logistic is tailored within MTO while TSCM focuses on consolidation and mass approach. In TSCM, uncertainties imply selling out the stock, while in MTO, uncertainty is treated by holding components as buffers (Gunasekaran & Ngai, 2005, p 425).

Reference	Traditional supply chain	Build-to-order supply chain
Marketing	Push-sell from stock	Pull – build to customer order
Production	Focus on level and stable schedules: fixed order lineup	Customer demand focused on supply chain flexibility
Logistics	Mass approach – non-differentiated	Fast, reliable, customized
Customer relationship	Dealer-owned	Shared across the extended enterprise
Managing uncertainty	Finished goods inventory buffers	Strategic part buffers and information management
Finished goods inventory	High stock control	Low, condensed dealer stock levels
Suppliers	Long lead times	Collaborative/responsive

Figure 3-14: The major differences between TSCM and MTO/BTO (Gunasekaran & Ngai, 2005, p 425).

The MTO supply chain (MOSC) can be defined as followed (Gunasekaran & Ngai, 2005, p 427):

"MOSC can be defined as a value chain that activates the process of building products based upon individual customer requirements and by leveraging information technology and strategic alliance with partnering firms for required components and support service such as logistics. The aim in MOSC is to meet the demand of individual customers with a short lead time and minimizing inventory and production costs along the value chain".

Gunasekaran & Ngai (2005, p 444) present a framework to develop MOSC. The major issues concern four main areas: Organizational competitiveness, development and implementation of MOSC, operations of MOSC and IT. The framework is presented in Figure 3-15.

- ***Organizational competitiveness***

Strategic planning considering both internal and external factors is essential. Factors such as economics, politics and market conditions have significant implications when developing MOSC. Also, product innovation, information technology, business risk and barriers to entry should be considered. Since MOSC implies global SCM, the environmental factors must be considered from a global perspective (Gunasekran & Ngai, 2005, p 445).

- ***Development and implementation of MOSC***

Development starts with the design of products and corresponding procurement strategies. The process involves introducing a customer-supplier partnership as well as integrating an enterprise resource planning system (ERP-system) between the participants. Cluster of components and modularity needs to be addressed, as well as after service and an effective logistic chain. Measures and metrics must be developed to evaluate the performance of the MOSC (Gunasekran & Ngai, 2005, p 445-446).

- ***Operations of MOSC***

This implies planning and forecasting decisions as well as coordinating and supervising in real-time mode. Decisions regarding inventory and production buffers must also be addressed. Operation managers in MOSC need to be skilled in using and making decisions with the help of ERP-systems, coordinating resources and production. Metrics and measures should be applied to monitor in-time deliveries and quality levels **(**Gunasekran & Ngai, 2005, p 446).

- ***MOSC and IT***

MOSC must use information technology in order to integrate suppliers and customers in the supply chain. Information managers are responsible for identifying a suitable ERP-system that communicates both upstream and downstream in the chain. The link between customers and suppliers is essential. The system should monitor tangible (inventory levels, manufacturing cycle times, defect rates), intangible (employees motivation, team work, brand), financial (profit, revenues, sales) and non-financial (inventory turnover, throughput time, setup times) performance indicators and their strategic impact on the business (Gunasekran & Ngai, 2005, p 446).

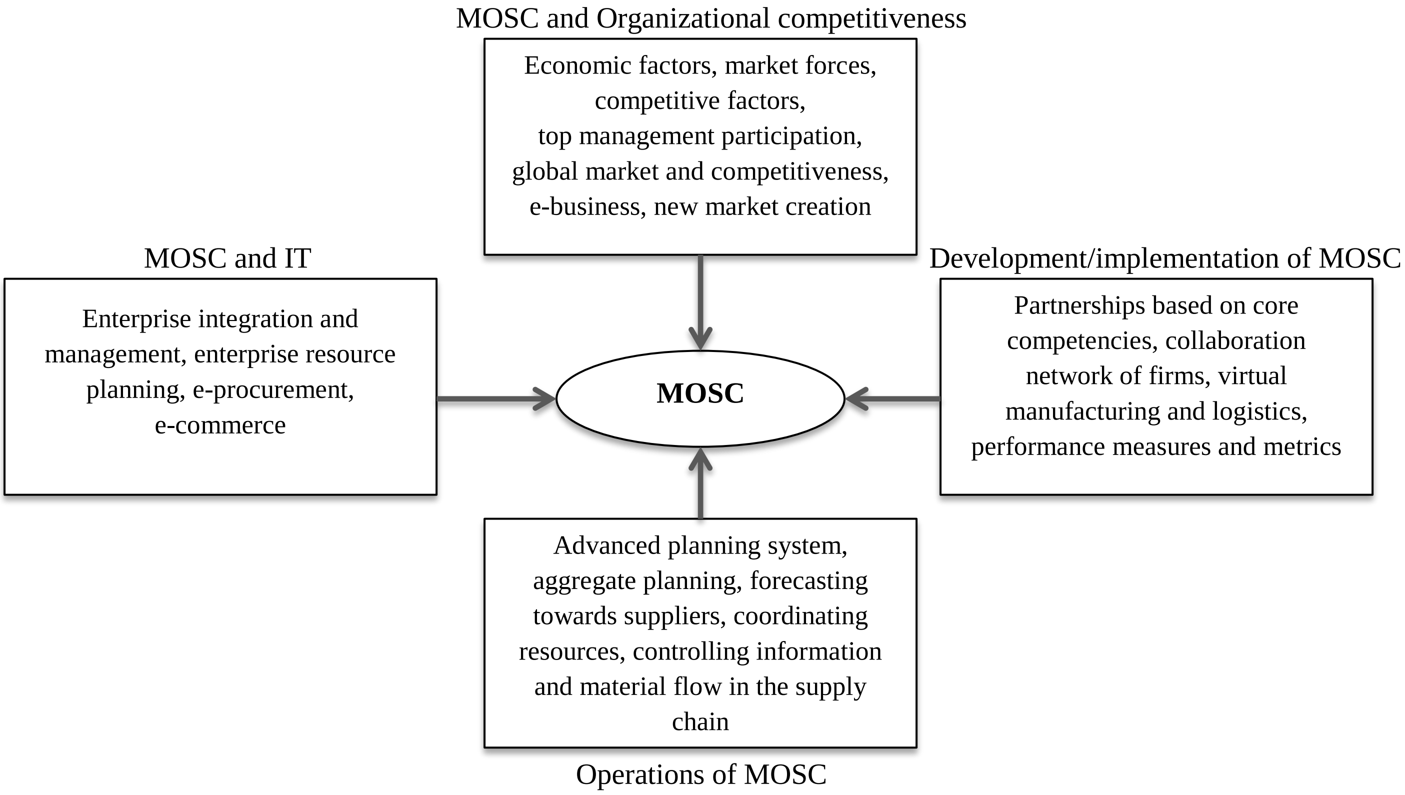


Figure 3-15: MOSC development (Gunasekran & Ngai, 2005, p 444).

In order to understand different manufacturing approaches, it is important to distinguish two segregated supply chain points. **The supply chain decoupling point (SCDP)** is the interface between the push and pull part of the supply chain. Here, the production goes from build-to-forecast to BTO. The purchased supplies and in-house made components are stored and the inventory levels determined by stochastic methods. The customized process is initiated in the pull system after the customer order arrives, shown in Figure 3-16 (Blecker & Adelkafi, p 5). **The differentiation point (DP)** is where variety increases in the assembly line. An assembly line can consist of several DPs, however it is more advantageous to delay the first one downstream in the process. When having a couple of standardized procedures before the first DP, the SCDP can be moved downstream the production, hence postponing the variety (Blecker & Adelkafi, p 6).

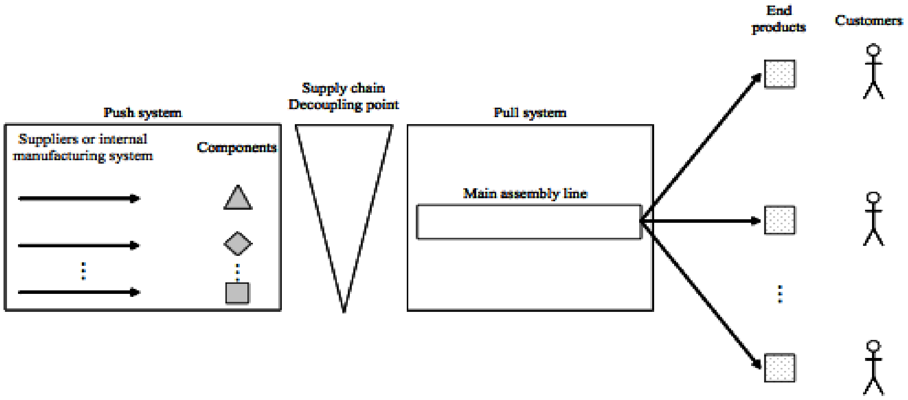


Figure 3-16: The SCDP (Blender & Adelkafi, p 5).

3.4 Process management

3.4.1 The process definition

Ljungberg & Larsson (2001, p 192) define a process as *a repetitive used network of linked activities that use resources and information in order to transform "object in" to "object out", from identifying to satisfying the customer needs*. Bergman & Klevsjö (2010, p 457) explain the concept as *a network of repeated activities, with the objective to create value to external or internal customers*. A process can also be described as *a number of cooperative or by each other affected activities that transform input to output* (www.iso9000.org, 111020).

3.4.2 The process components

A process consists of five components, which are all mentioned in the process definition. An **object in** triggers and starts the process, and the transformed and value added object is called **object out**. **Activities** represent the process network, consisting of operations that transform object in to object out. Activities can be decomposed into sub activities, revealing a detailed workflow. Activities require **resources** to perform operations and **information** in order to be supported and supervised. (Ljungberg & Larsson, 2001, p 194-196) The different process components are illustrated in Figure 3-17.

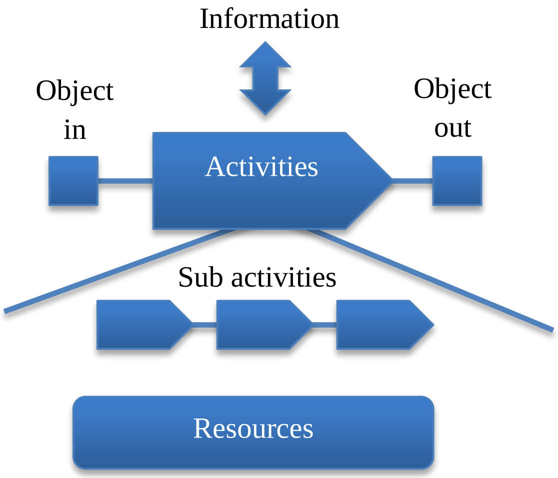


Figure 3-17: The five different parts of a process (Ljungberg & Larsson, p 194).

3.4.3 Identification of processes

An organization's processes must be identified in order to be developed. There are three different types of processes that must be considered (Ljungberg & Larsson, 2001, p 184):

- **Core processes** explain the purpose of the business, actualizing the business idea, building the foundation of the organization (Ljungberg & Larsson, 2001, p 82).
- **Support processes** make core processes function efficiently. Support processes should be evaluated regarding how effective they support core processes, and not regarding the value they create (Ljungberg & Larsson, 2010, p 185).
- **Management processes** control, monitor and coordinate the core and support processes (Ljungberg & Larsson, 2010, p 186).

Different techniques can be applied when identifying and mapping processes. The most common ones are (Ljungberg & Larsson, 2001, p 204-205):

- A **walk through** implies one or several persons literally walking through the process, interviewing employees and illustrating the process graphically. It is a time effective technique, however only the performers obtain the holistic perspective of the process.
- During a **virtual walk through**, representatives from all functions affected by the process construct the process map together by combining perspectives from all participants.
- Establishing a **process mapping team**, with representatives from all functions affected by the process, results in a better understanding of the process execution. However, each of the participants must be educated in process mapping, implying the technique to be time demanding.

3.4.4 Process measurement system requirements

The measurement of a process is of vital importance when evaluating status and progress. There are certain requirements that a process measurement system must fulfill, described in Figure 3-18 (Ljungberg & Larsson, 2001, p 234).

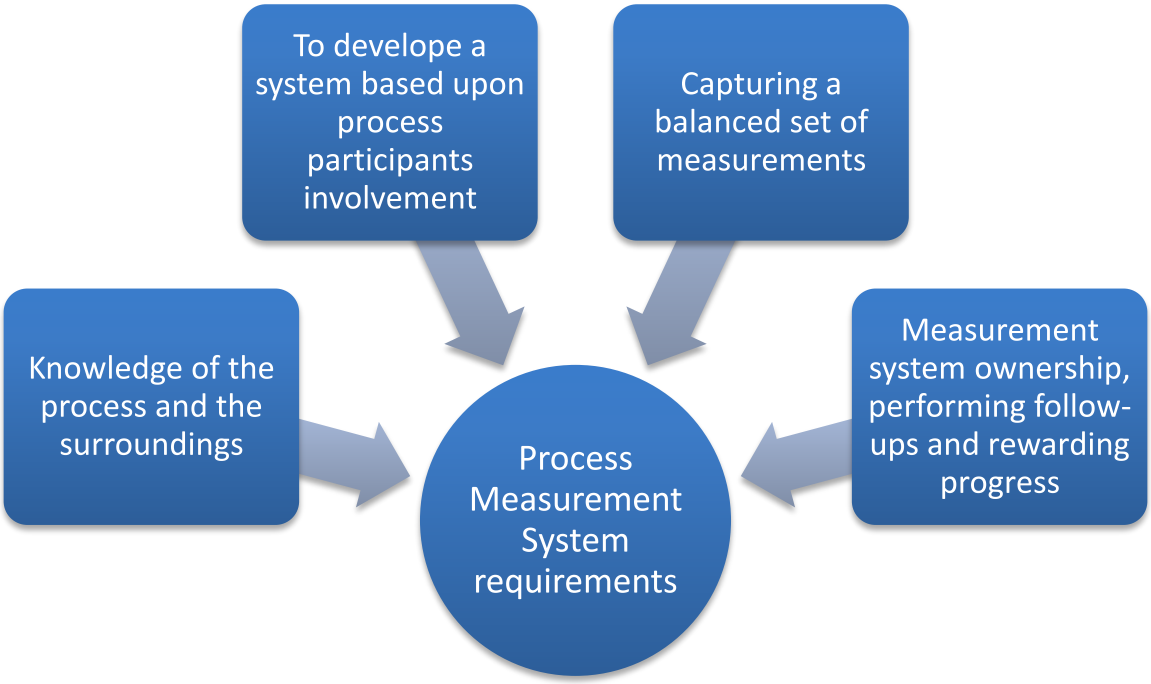


Figure 3-18: The process measurement system requirements (Möller & Sahleström, 2011).

4 Empirics

In this chapter, the product and the companies participating in the master thesis are presented. Each supplier's order process and manufacturing system is described as well as a comprehensive presentation of their quality work.

4.1 The product

4.1.1 The custom made worktop

The custom made worktop, the PERSONLIG range, has been part of the IKEA kitchen range for 15 years. In contrast to the general IKEA products, the PERSONLIG range is not mass produced. Each custom made worktop is unique, produced according to specific customer requirements.

The worktop variables that can be customized are presented below and summarized in Figure 4-1:

- **Materials** – There are four different worktop materials of choice: Laminate, solid wood, stone and acrylic. There are 27 different prints of laminates, and three solid wood materials: Oak, Beech and Birch. Laminate worktops dominate the quantity of the range and have the highest turnover. Solid wood worktops are sold in smaller quantities than laminate worktops, but have an increased market share when measuring turnover. Therefore, the materials laminate and solid wood have been examined in the master thesis.
- **Size** – The worktop length can be chosen between 50-4000 millimeters, the width between 50-1225 millimeters and the depth either 38 or 76 millimeters.
- **Shapes** – The shapes can be generalized as single-, double- and triple-cuts or radius forms. However, from the suppliers' perspective, there are almost no limitations regarding the shape of the worktop.
- **Edges** – Solid wood worktops has fixed edges, whereas for laminate worktops the following varieties can be chosen.
    - The original front post formed edge in laminate.
    - Polypropylene-edges (PP), which is a plastic edge.
    - Extra post formed edges.
    - Aluminium or stainless steel edges.
    - Three wooden edges made of oak, beech and birch.
- **Sinks** – There are 10 different sinks, produced in either China or Greece. A cut out is made for the sinks, which is then glued on the underside of the worktop. This is a work method that separates IKEA from other kitchen element retailers who assemble the sink from above, using screws as stabilizers.
- **Cut outs** – The customer can add specific cut outs for different kitchen machines, such as a garbage disposal unit.
- **Pre-milled surfaces** – Pre-milled surfaces, e.g. for stoves, is an option. The milling operation is performed like an incomplete cut out, where some chips on the underside of the worktop are left

intact for stabilization. The remaining part is cut out by a craftsman during the installation of the worktop at the end customer.

- **Joints** – A joint implies that a connection is milled in two separate worktops, enabling the customer to connect them when installing the product.

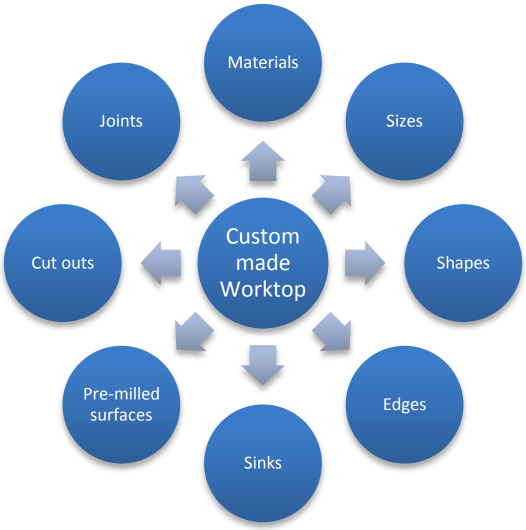


Figure 4-1: Variables of a custom made worktop (Möller & Sahleström, 2011).

4.1.2 The general process

The general process from customer order to worktop delivery as well as the claim procedure are described below and illustrated in Figure 4-2.

4.1.2.1 The complete order process of a customized worktop

A custom made worktop must be ordered in person at an IKEA department store. The customer brings a drawing, which the seller transfers to a computer system by using a drawing program, where it is possible to change worktop variables according to customer requirements. There are certain limitations of variables, and the computer system does not accept the creation of a product that is outside the scope. The customer signs the drawing, confirming the correct measurements, additions, materials etc. The seller registers the order in the ECIS system, a system shared by IKEA and suppliers, implying that the worktop supplier can download the order the day after. The worktop is manufactured according to drawing and customer order, having a fixed supplier handling lead time of ten days. The product is then transported to one of several local service centers (LSC) located in each country, or a central distribution center (CDC) in Dortmund, for further distribution to the customer.

4.1.2.2 The claim process

When a claim reason occurs, the customer contacts the customer service in the country where the worktop was purchased. The customer service categorizes the claim as a seller, supplier or transport mistake. However, a well-performing claim process is of true importance for the suppliers, implying traceability and possibilities to take actions. At the time of the master thesis execution, the three participants had different opinions regarding the accurate claim rate ascribed to the suppliers. IKEA claimed that both of the suppliers had a claim rate of 4 %, measured in number of orders. This did not correspond with the opinion of neither Lechner nor Danform, claiming their claim rate to be approximately 1,3 % and 1,25 % respectively. For each claimed order, IKEA charges the supplier a claim penalty cost of 300 euros.

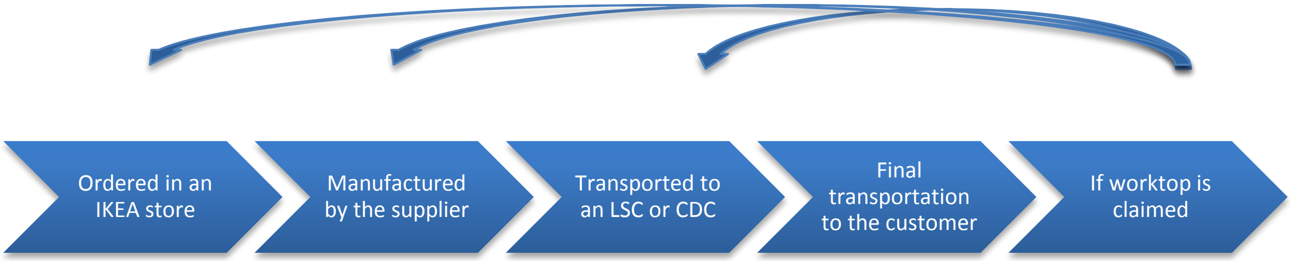


Figure 4-2: The general process of a worktop (Möller & Sahleström, 2011).

4.2 IKEA; The organization and work methods

4.2.1 Company presentation

IKEA was founded 1943 by Ingvar Kamprad and has grown rapidly since the first department store opened in 1957. The IKEA Group had a total sale of 23,1 billion euros in 2010, illustrated in Figure 4-3, and is represented in 26 countries with 280 department stores. The department stores are mainly located in Europe as seen in Figure 4-4, although IKEA market shares are growing in Asia, Australia and USA. The leading countries regarding sales are Germany, USA, France, Great Britain and Italy while the leading countries from which IKEA purchases material are China, Poland, Italy, Germany and Sweden (statistics from 2010). The IKEA Group employs 127 000 individuals, who mainly works in the retail sector.

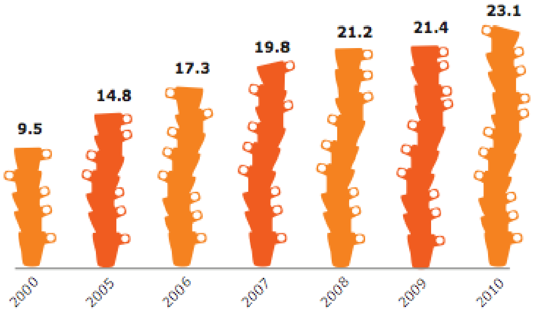


Figure 4-3: IKEA sales 2000-2010 (www.ikea.com).

Figure 4-4: IKEA department stores (www.ikea.com).

The vision and business idea of IKEA are the following:

- **The vision** – To create a better everyday life for the many people.
- **The business idea** – To offer a wide range of well-designed, functional home furnishing products at prices so low that as many people as possible will be able to afford them.

4.2.2 The IKEA organization

The IKEA group was founded 1982 in order to establish a company organization with focus on independence and long-term approaches, and is owned by Stichting INGKA Foundation. The foundation has two main objectives: To reinvest in the IKEA Group and to act a charitable foundation. The IKEA Group franchises the retail concept from Inter IKEA System and is responsible for market entry question and where the franchising concept is to be preferred, e.g. Dubai and Qatar. The IKEA Group consists of three parts:

- **Range strategy, product development and supply chain** – IOS and trading offices.
- **Retail** – Warehouses.
- **Industrial group** – Swedwood and Swedspan.

When retail had been defined during the 1980s, there was a need for an organizational function that could provide the assortment. Therefore, IOS was founded. The IOS organization consists of business areas with material leaders and category leaders as coordinators. Within the business areas there is a focus on retail with responsibility for demand, introductions, pricing and product design. The needs of the business areas are communicated to the category leaders. A category leader is responsible for a certain material within a certain production process, and reports to a material leader. A material leader is responsible for all purchase of a certain material. This implies that different category leaders can answer to the same material leader. The purpose of the category and material leaders is to coordinate the global purchase for all business areas, linking the two sides; retail and supply.

IOS needs an organization handling the connection between assortment and suppliers; the trading offices. There are approximately 40 trading offices globally with headquarter in Pratteln, Switzerland. Until 2008, trading offices were responsible for specific geographical areas, handling all supplier activities within the given region. Since a trading office was evaluated by the annual purchased value, a strong competition between the offices occurred, which pressed prices but ignored quality. The trading offices were therefore divided into categories that increased the expertise and the communication with the suppliers. IKEA Trading Dortmund is together with Älmhult and Kaunas part of IKEA Trading Northern Europe, which represents 18 % of total purchase. The categories at the Dortmund office are e.g. green plants, flooring, lighting and custom made worktops.

Therefore, IOS is responsible for the design, specifications and forecasting of the IKEA assortment, while IKEA Trading is responsible for the supply chain and the supplier relations. Consequently, Trading provides Retail with the assortment defined by IOS, illustrated in Figure 4-5

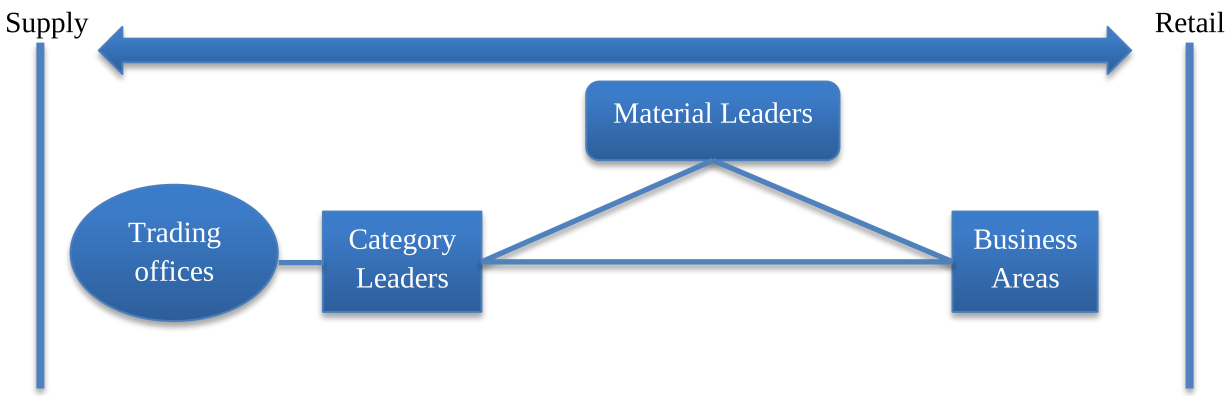


Figure 4-5: The IKEA organization (Möller & Sahleström, 2011).

4.2.3 IKEA Trading

A trading office consists of Business Teams, each lead by a Business Development Manager (BDM). The other roles are:

- **Business Developer** – Commercial questions.
- **Supply planer** – Transportation and delivery.
- **Technician** – Audits, documentation and supplier relations.

A business team handles the supply chain and the supplier relations for one or several categories, reporting to the responsible category leaders. The handling of supplier documentation is mainly performed through four different systems:

- **DWP** – Dimension, weight and packaging system. The system handles all transportation variables connected to each article, such as sizes, amount on a pallet and delivery dates. A technician at IOS uploads the articles and the suppliers are responsible for filling in the required data.
- **Contract review** – The supplier contract is initiated by IOS, however IKEA trading handles the communication with the supplier.
- **PDOC** – A product documentation system where each article is connected to technical descriptions, requirements, drawings and packing instructions. All the required documents are created and connected by IOS.
- **Connect** – The system handles all documentation regarding test reports, self-declarations and certificates connected to each article.

4.2.4 Product documentation

The product documentation of the PERSONLIG range has been developed during the last years. This is because the product is quite recently introduced in the IKEA assortment, and differs from traditional IKEA products regarding variety and flexibility. The nature of the product implies that everything cannot be described and stated. The main documents for an IKEA product are:

- **Technical descriptions** – Contain requirements on materials, handling and execution of tests, changes, packaging and risk analysis.
- **Drawings** – Contain detailed drawings of the specific product.

- **Labels** – Contain what information that must be available in order to ensure effective traceability. This includes e.g. production date, article number, name, picture and barcodes.
- **Packing and handling** – Contain all information regarding packaging and handling.
- **Other specifications** –This includes e.g. specifications regarding instructions, specific materials, surfaces, chemical substances and packaging.

4.2.5 The IKEA Supplier Quality Standard

The IKEA SQS contains quality requirements of which a company is evaluated upon in order to be established as an IKEA supplier. The IKEA SQS consists of 8 Go/No Go requirements, meaning that the supplier must fulfill all 8 under all circumstances. If one of these requirements is to be considered as “not approved”, the purchase from the supplier is limited or directly blocked. The 8 Go/ No Go requirements are presented below, however in shorter versions. Apart from the IKEA SQS, IKEA also uses the IKEA IWAY, which is a non-product quality related code of conduct towards suppliers and will not be further described.

1. The product must fulfill customer experienced product quality (CEPQ).
2. All products must pass final inspection, and the final inspection procedure must be based upon KPI parameters agreed together with IKEA.
3. The final inspection must be carried out by an inspector that has knowledge of IKEA product requirements and CEPQ.
4. Special processes must be implemented with process schemes, measurements and testing.
5. The supplier must identify and segregate all non-conforming products.
6. The supplier must have a documented test status summary with valid test reports, self-declarations and certificates.
7. The supplier must assure that all products are produced according to valid IKEA product documentation.
8. The supplier must assure that requirements and conditions are communicated to sub-suppliers.

Apart from the 8 Go/No Go quality requirements, there are 7 areas of which IKEA evaluates its suppliers, highlighting improvement potentials. These should not be seen as crucial, however still critical, and IKEA strives towards that the suppliers shall fulfill as many improvement potentials as possible. The 7 areas are briefly described below.

1. ***Management***

The management must show commitment towards quality, stating a quality policy. The supplier should, together with IKEA, determine KPI parameters in order to increase customer satisfaction and decrease COPQ. The management must also ensure the performance of internal audits as well as monitor and evaluate quality performance and QMS. The management must continuously improve the KPI parameters by performing root-cause analyses. Also, the management is responsible for the documentation of the IKEA SQS requirements.

2. ***Start-up process***

The supplier must have a start-up process that ensures required product quality from IKEA, including CEPQ and a well-documented production plan. Also, a production risk assessment must be developed where CTQ parameters regarding products, processes and maintenance are identified. The supplier must also execute a FMEA on each CTQ in order to identify risks and risk preventions. Each sub-supplier affecting a CTQ must be evaluated and IKEA documentation and requirements must be communicated. A capacity assessment of the CTQ processes must also be carried out. Finally, the supplier must continuously improve all parts of the start-up process.

3. Secure incoming goods

The supplier must secure incoming goods by creating an inspection plan, including tolerances. The supplier shall have a minimum level of inspection and must also continuously improve the inspection process.

4. Production control

The supplier must secure the CTQ product parameters through inspections, given tolerances, data collection, measurements, maintenance as well as continuously improvements.

5. Final inspection

The supplier must ensure that all products pass a final inspection, which must be performed according to KPI parameters agreed upon together with IKEA, in order to secure quality requirements before delivery to end customer. This includes fulfilling CEPQ.

6. Document and sample control

The QMS must, for a given activity, state *what* to do, *how* to do it, *who* is doing it as well as *when* and *where* it is done. The IKEA supplier must also describe how the documentation of the QMS is established and maintained. In addition, the supplier must be able to demonstrate how to receive, store and update IKEA documentation in order to secure production according to valid documents.

7. General requirements

The general requirements involve the facilities, the capability to identify and segregate all non-conforming products, how to work with preventive and corrective actions as well as execution of measurement system analysis (MSA) and traceability.

4.3 Lechner

4.3.1 Company presentation

Lechner is a producer of custom made worktops, founded in 1971 and situated in Rothenburg ob der Tauber. The company produces worktops in laminate, solid wood, ceramic, stone, acrylic and glass. Lechner has two more production facilities, located in Hungary and Sweden. Lechner has cooperated with IKEA for ten years, with a short break during 2004-2006, and the PERSONLIG range corresponds to 50 % of Lechner's production volume. Lechner supplies laminate worktops to IKEA in Denmark, Finland, France, Italy, Norway, Poland, Portugal, Sweden, Spain and Czech Republic. Solid wood worktops are supplied to the mentioned countries, adding Switzerland and Austria.

Lechner's vision is to be the best in the worktop business, although this vision is not stated publicly. Lechner considers its key factors of success to be the product range, the employees and the supplier and customer relations. Lechner strives towards as much in-house production as possible, and is always eager to test new materials. In order to master different materials and the required production flexibility, the employees must be skilled handcraft men. Therefore, HR and in-house training are crucial. The short-term goal of Lechner is to get return of investment on the new facility in Sweden. The long-term objectives are to gain more customers and to expand to other countries together with an even more varying production range. However, Lechner will continue its step-by-step development to ensure sustainable company growth. The company will not seek fortune on other markets; the objective is to be world class in the worktop business.

Lechner claims that MTO production is difficult since it is dependable on the workforce. Work instructions can be applied to a certain limit; however success lies in having many specialists within the production. This must be combined with technology in order to act as a mass producer towards customers. Major obstacles to overcome are mastering the right product mix as well as having an effective logistic system. Lechner strives towards reducing waste in the production without reducing the core capability, the human capital. From Lechner's perspective, the cost of a worktop should be fixed, implying that the profit should be gained through increased efficiency.

Lechner has three CEOs; sales, production and finance manager share the CEO responsibility. The production of laminate and solid wood worktops in Rothenburg ob der Tauber consists of two production halls. Departments of interest in this master thesis are the engineering, production, IT, purchasing as well as the order department. The company has 600 employees and a turnover of 70 million euros.

4.3.2 The process from order receiving to production hall

4.3.2.1 From order receiving to production planning and control system

The order department connects daily to the ECIS-system, from which orders are transferred to the database at the supplier, where information such as order numbers, delivery week and drawings are saved. Order papers and drawings are sent to the order department through a printer. Firstly, the order is manually compared with the order information in the supplier's database, ensuring the correspondence between drawing and order. Secondly, the order and drawing are typed into the order receiving system. This is performed manually by typing in material, color and thickness followed by length, depth and edges. Depending on the appearance of the worktop, there are possibilities to add e.g. shapes, joints, cut-outs and sinks. Afterwards, the order is automatically compared with the saved order information in the supplier’s database. If information corresponds, the order is transferred to the supplier’s production planning and control system (PPC system). If information does not correspond, the order is blocked and the operator must take action e.g. performing a call back to the concerned IKEA department store. The order process is described in detail in Appendix 1.

A call back is made when any vagueness’s have occurred e.g. insufficient or wrongly stated information. A call back is performed by sending a message to the concerned IKEA department store that answers the question, in some cases IKEA needs to contact the end customer. The supplier must make the necessary call back within 24 hours after order receiving, and the department store must reply within the next 24 hours. However, the complexity of the question and the responsiveness of the department store imply that these time frames are often extended. When a call back is made, the order is put on hold until an answer is received.

4.3.2.2 From production planning and control system to production hall

The supplier’s PPC system is time based, meaning that the order is given a fixed entrance date in the manufacturing, based upon the delivery date. The fixed system implies that storage of finished goods is kept low, however work intensity within the manufacturing varies heavily. The supplier does not have the possibility to even out the production over certain time frames, meaning that planning and coordination of required manpower must be performed on a daily basis. This also implies a risk if a machine would break down, since the worktops that should be processed in the particular machine on the particular day can not be rescheduled.

Another disadvantage with the PPC system is the gathering of information. Since production flows are mainly not pre-determined but decided by operators, further explained in chapter 4.3.3.2, scanning the worktop at each work station is not mandatory, nor necessary. Consequently, valuable information is not registered. The PPC system could be upgraded and overcome the mentioned disadvantages, however the process would last 4-6 month and require full attention of the IT-department. Therefore, it is a strategic decision for the future.

The orders and drawings are, based upon the entrance date, printed and delivered daily to production hall 1 or production hall 5, further explained in chapter 4.3.3.1.

4.3.3 The manufacturing system

4.3.3.1 Production halls

Lechner has two production halls for laminate worktops, hall 1 and hall 5. In hall 5, only laminate worktops are produced, whereas in hall 1 the production of solid wood worktops also takes place. Hall 1 contains both automatic and manual work stations, where most transportation is handled manually. In hall 5, the manufacturing is almost completely automatic and most of the transportation between stations is performed with conveyer belts. There are two main differences between hall 1 and hall 5. Firstly, due to the manual work stations, more complex processes can be performed in hall 1. Secondly, the production control system in hall 5 is fully automatic, whereas in hall 1, the operators decide the production flow of each worktop based upon their experiences. Basically, this implies that the operator knowledge equals the production control system.

Figure 4-6 and Figure 4-7 shows the layout of hall 1 and hall 5 respectively. For IKEA worktops in hall 1, the work stations “Hüllhorst”, “Schichstoffsäge” and “Elementskante” are never used. In hall 5, the workstation “Hinterkante” is used seldom. The process of each workstation is explained in Appendix 2.

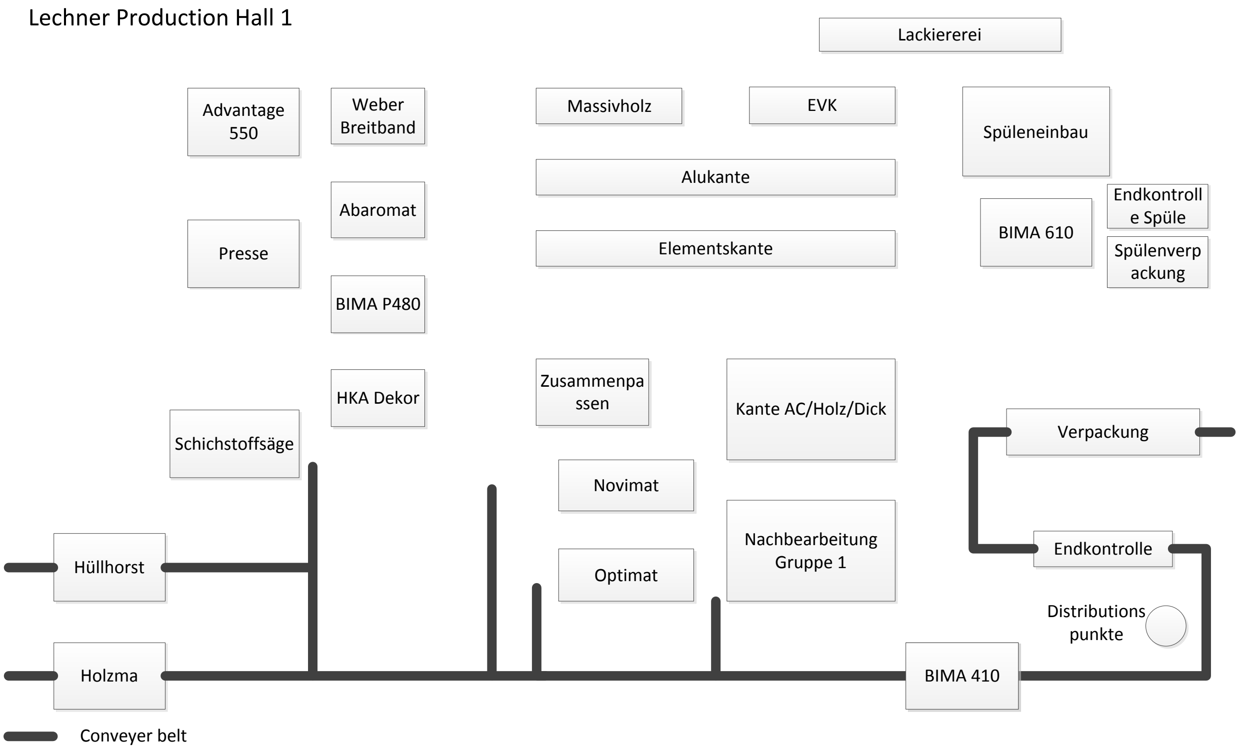


Figure 4-6: Layout of Lechner production hall 1 (Möller & Sahleström, 2011).

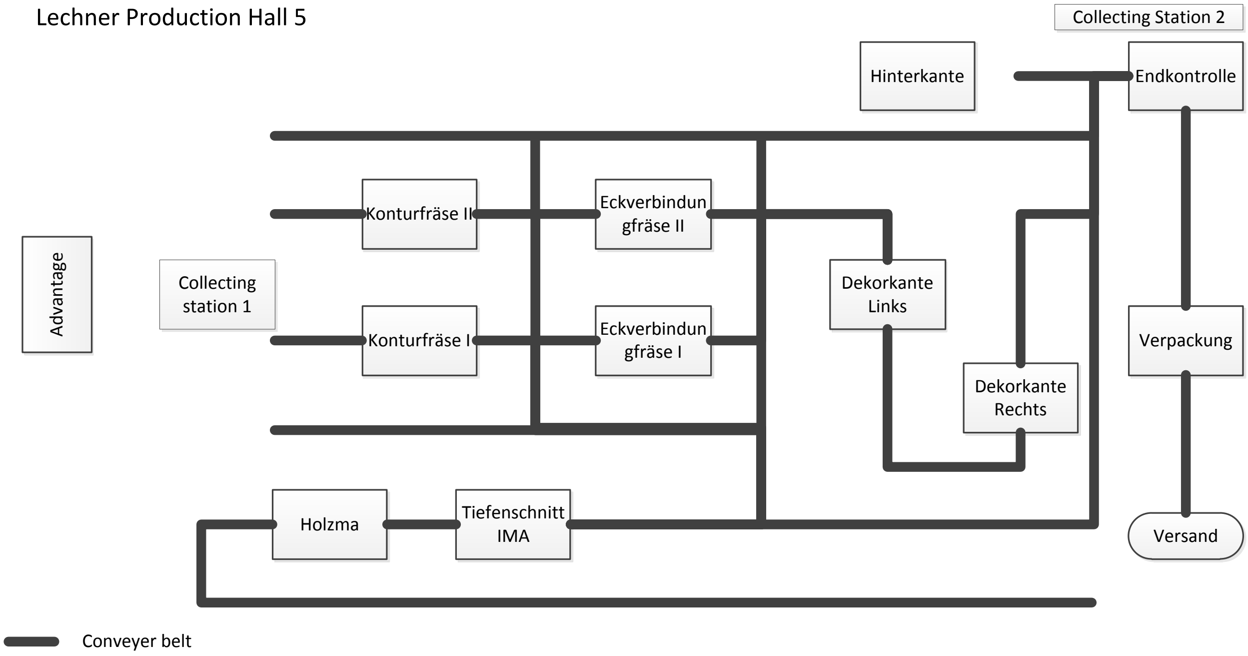


Figure 4-7: Layout of Lechner production hall 5 (Möller & Sahleström, 2011).

Approximately 90 % of all IKEA laminate worktops start their manufacturing process in hall 5, where approximately 70 % of all IKEA laminate worktops are also finished. In which production hall the manufacturing of a specific laminate worktop starts depends on the location of the stored material. That means that storage location of laminate rather than worktop complexity determines in which production hall the laminate worktop starts its manufacturing process.

The production flows in the two halls are intertwined at several work stations, where worktops enter hall 1 from hall 5. The connection points in hall 5 are collecting station 1 and collecting station 2. Collecting station 1 consists of 7 wagons, where worktops are distributed to 8 work stations in hall 1. Collecting station 2 consists of 3 wagons, where worktops are distributed to 2 work stations in hall 1. The difference in number of wagons and processing stations are due to product variety, separating worktops with longer and shorter lead times.

4.3.3.2 Production flows

Both production hall 1 and production hall 5 are single-unit manufacturing systems; however they do not have small production volumes. The manufacturing layout in hall 1 can be described as a complicated function oriented layout. Machines with the same functions are somewhat placed in the same area; however the flexibility of the manufacturing system and the product variety result in an ambiguous production flow. The material handling is truly complex since the worktop flows can take many different paths with long internal transports, even between the production halls. Also, there are buffers within the manufacturing system implying queuing time before and after each work station.

The production flows of laminate worktops for hall 1, illustrated in Figure 4-8, is a simplified flow chart, including work stations where IKEA worktops are processed. Only general flows are shown, and stations with similar functions but different materials, such as Alukante/EVK and Optimat/Novimat, have been merged together for easier understanding. Text connectors are used from production hall 5 and the distribution station, and production flows that are not typical for IKEA worktops have been distinguish.

The production flows of solid wood worktops for hall 1 can be seen in Figure 4-9. The processing of solid wood worktops has been restricted to fewer stations, which results in simpler production flows. As seen in Figure 4-8 and Figure 4-9, some work stations process both solid wood and laminate worktops. It should be stressed that the station “Lackiererei” oils solid wood worktops, and that lacquer is not used for PERSONLIG laminate worktops.

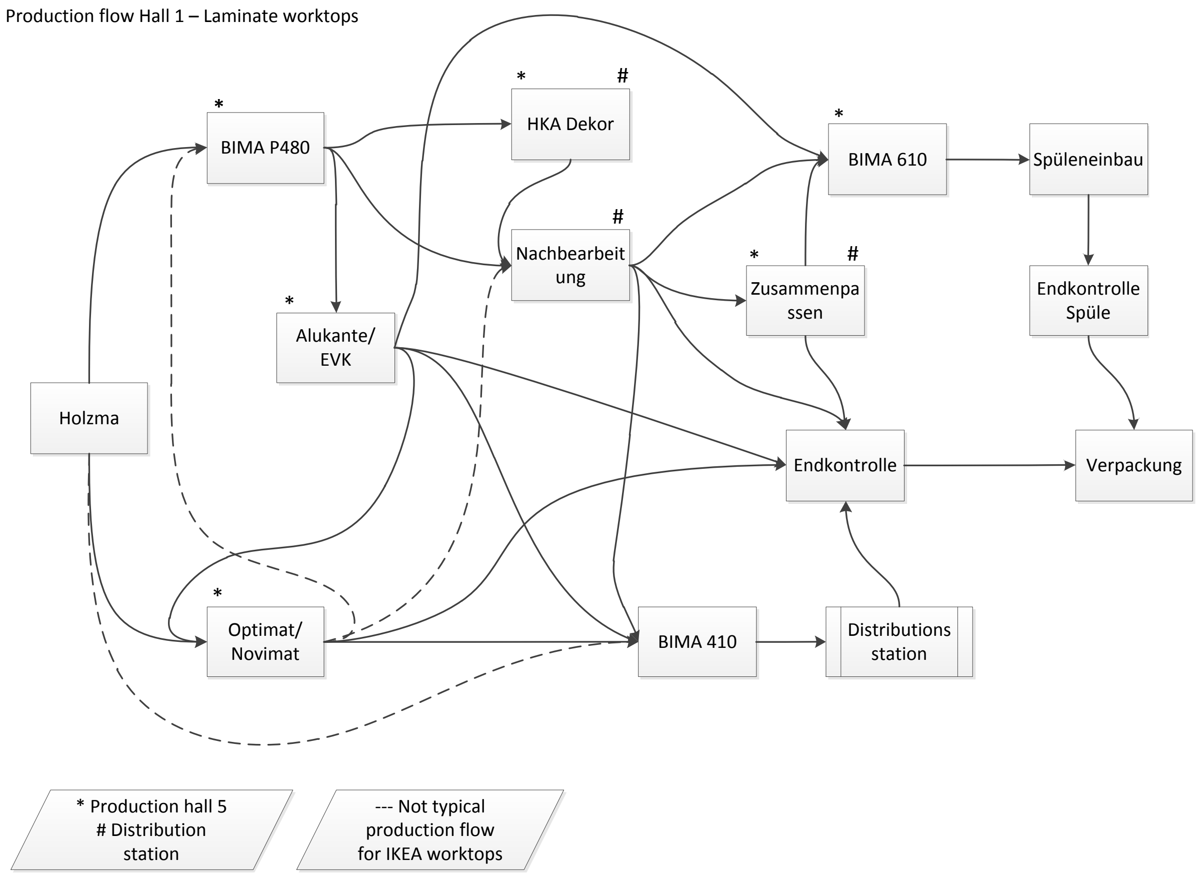


Figure 4-8: Production flows in Lechner production hall 1 for laminate worktops (Möller & Sahleström, 2011).

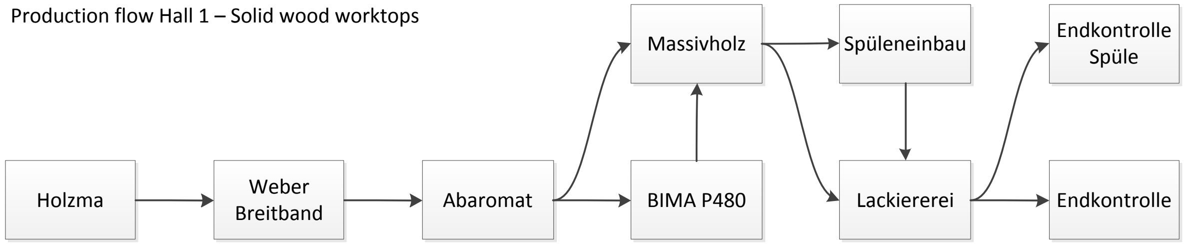


Figure 4-9: Production flows in Lechner production hall 1 for solid wood worktops (Möller & Sahleström, 2011).

The manufacturing layout in hall 5 can be described as a function oriented line production, where machines are arranged according to their function with a line production perspective. The automatic material handling enables a higher production rate and a clear overview of the worktop production. The manufacturing system has buffers before “Konturfräse I & II”, “Advantage”, “Eckverbindungfräse I & II” and hall 1.

The production flows for hall 5, illustrated in Figure 4-10, is a simplified flow chart, where stations with the same functions have been merged together for easier understanding. IKEA worktops that can not be finished in production hall 5 are worktops with one or more of the following variables; single cut, double cut, triple cut, wooden edge, aluminium edge, post formed edge and sink. These worktops will be transported to production hall 1.

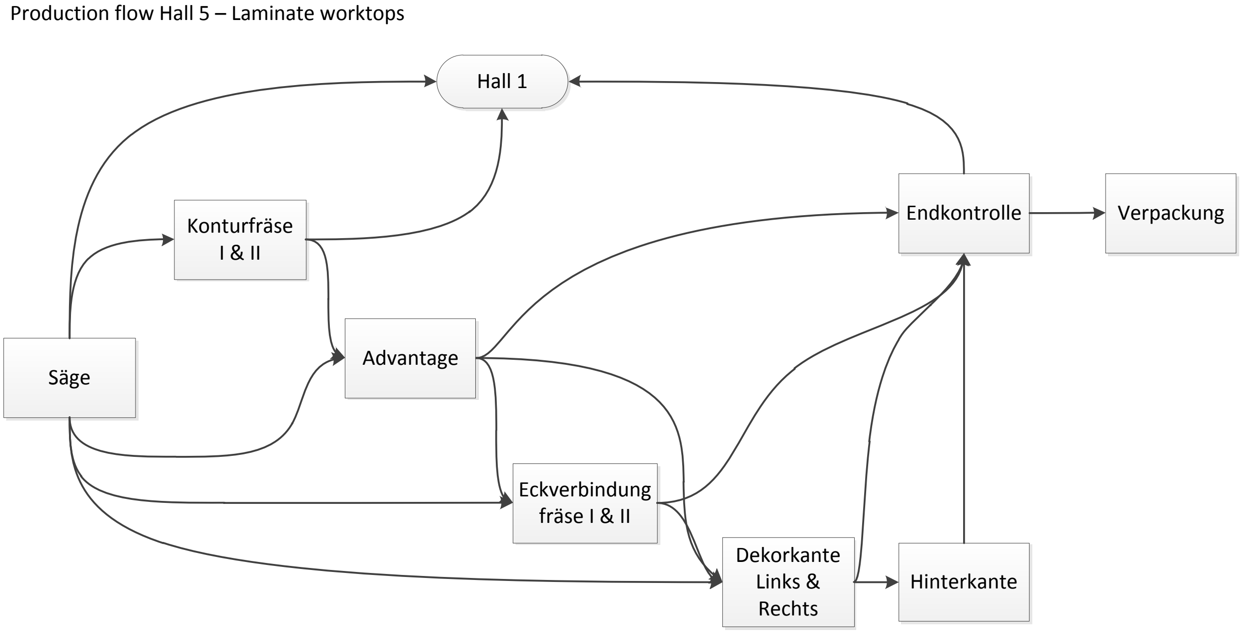


Figure 4-10: Production flows in Lechner production hall 5 (Möller & Sahleström, 2011).

4.3.4 Measurement system

The supplier currently uses two measurement systems, one for production hall 1 and one for production hall 5. Both measurement systems are used to register rejections.

In production hall 1, there are four collection points for rejections, evenly distributed in the manufacturing and each connected to a number of work stations. A rejected worktop is transported from a work station to a collection point by operators. If there is any uncertainty regarding if the worktop should be rejected or not, a shift leader is to be called to the work station to decide the appropriate actions. A shift leader conducts a daily registration of rejections at the collection point, by typing it into the measurement system. The current measurement system in production hall 1 has four variables for describing rejections, which is a mixture of quality parameters and rejection causes. The supplier's previous measurement system had additional variables of choice, though its use was determined as too difficult and unreliable due to incorrect registration.

The supplier has neither documentation nor descriptions in production hall 1, explaining which work stations that belong to which collection point. At the collection points, it is not possible to determine at which work station the rejection was detected.

In hall 5, there are two collection points situated at each collecting station, demonstrated in Figure 4-7. Due to standardized and automatic production flows, there are no shift leaders required in hall 5. Therefore, operators at each collection station are responsible for the segregation and registration of rejections into the measurement system. The measurement system in hall 5 contains only quality parameters and has more variables of choice than in hall 1, since no degradation of reliability has been detected.

4.3.5 Quality related departments

There are many departments at the supplier that directly or indirectly affect product quality e.g. product development and IT. However, there are three departments that are more directly related to the supplier's quality work, described below.

4.3.5.1 Quality department

The supplier's quality department was founded in 2009 and assigned a full-time quality manager in December 2011. The former quality manager was Mr. Thomas Beyl, CEO responsible for finance and HR. Mr. Beyl stated the quality approach as "quality is making every customer satisfied, and must be a part of everyone's work*"*. The quality department consists of nine employees within product testing, product quality control in the manufacturing, product documentation and quality improvements. Department personnel claim that there is an absence in use of structured work methods e.g. quality projects are performed, although there is no standardized project plan. The department is responsible for developing structure and coordination of quality work as well as improving internal documentation.

The quality department reviews the supplier responsibility of customer claims that are estimated as manufacturing related. The department receives claims from the IKEA Key Account Manager and decides to accept the claim if it is determined as originated from the manufacturing facilities. If the claim is accepted, the claim is registered in the supplier database.

IKEA documentation is received, stored and updated by the two product documentation responsible. Department personnel state that there is weak communication of customer requirements, within the department as well as to the manufacturing, and that the external communication to IKEA is performed through too many communication channels, complicating the updating of documents.

4.3.5.2 Engineering department

The engineering department is newly founded and consists of five employees; one within product development, two within CNC programming and two within manufacturing analysis and improvements. CNC programs are normally automatically generated to each order, though when more complex milling operations must be executed, the engineering department must write new milling programs.

The department analyses data from the measurement system and takes appropriate actions. The personnel responsible for manufacturing improvements spend lots of time on the shop floor, gathering additional information, solving temporary problems and performing improvement projects.

The department introduced a suggestion system 2 years ago, which includes suggestion boards within the manufacturing as well as at departments, in order to collect suggestions for improvement and operator opinions.

4.3.5.3 Purchasing department

The purchasing department consists of three employees and is responsible for relations with as well as selections and evaluations of sub-suppliers. Sub-suppliers are evaluated upon several criteria, whereas the quality criterion is defined as material claim rate. The material claim rate is determined through inspections, which are structured and performed by the quality department. The purchasing department neither communicates the measured claim rate nor the evaluation results to sub-suppliers. The department is also responsible for ensuring sub-supplier acceptance and signing of necessary IKEA documentation.

Future department objectives are to improve costs of purchased goods, payments methods, sub-supplier evaluations as well as decreasing the sub-supplier base.

4.3.6 The Quality Management System

The supplier does not have a QMS. According to quality department personnel, a QMS should demonstrate how activities are performed, ensuring the correct quality performance, as well as providing documentation and maintaining process control. Department personnel also claim that the absence of a QMS reflects the general quality approach of the supplier, that processes and activities are poorly mapped and documented. The management has discussed an ISO-9000 certification, but nothing has yet been decided.

4.3.7 Quality control

4.3.7.1 Product quality control within the manufacturing

Product quality control is said to be performed throughout the production. Currently, except for the final control station, work descriptions at work stations do not exist, and instead, general management advices regarding control are used; “the dimensions should be measured every 5th worktop” and “each worktop should be checked for surface and material defects”. The supplier states work experience to be very important when performing product quality control.

Work descriptions within the manufacturing are only placed at the final control stations in both production halls. These work descriptions contain quality control procedures and measurement tolerances. The final control stations are stated as being 100 % responsible for product quality control of each worktop. Execution of control is performed by using measuring tape, templates for joints as well as inspecting the quality of surface and edges.

4.3.7.2 Process control within the manufacturing

The only manufacturing process documented at the supplier is the inspection process at the final control station.

The only work stations where process control is performed are at the CNC machines. This is performed in two ways. Firstly, every 60 minutes the joints of a randomly chosen worktop are controlled by use of templates. The process control results are not documented. Secondly, a monthly process control is executed by a final control station operator, through the joining of worktops that are processed at different CNC machines, performing a visual joint inspection. If the joint of the worktops is not satisfactory, a measurement test with tolerances on depth of the joint is performed. The monthly test is documented. If measurements are outside the tolerance limits of ± 1 mm, adjustments of the CNC machines in question will be performed.

4.4 Danform

4.4.1 Company presentation

Danform is a producer of custom made worktops, situated in Salzhemmendorf. Earlier, IKEA ordered the PERSONLIG range from a company called Danielmeyer. However, when the amount of orders increased, the CEO of Danielmeyer founded Danform in 2007 with the aim of serving only IKEA. Consequently, Danform has only one customer, selling IKEA custom made worktops in laminate to Belgium, Holland, UK, Austria, Switzerland and Germany. It should be noted that the supplier has production of solid wood worktops at the Danielmeyer facilities, but this has not been considered in this master thesis.

Danform does not have a vision, due to the fact that IKEA is the only customer. Instead, the objectives are to grow together with IKEA and be regarded as a trustworthy supplier with cooperation within quality, service and sales. This implies that other materials might be taken into consideration. The success factors of Danform are considered to be the experienced coworkers as well as a strong knowledge within IT. Danform has 60 employees and a turnover of 20 million euros.

The organization consists of the order department, the purchasing department and the production hall. The CEO and the production manager divide their work time between Danform and Danielmeyer, and some departments do support both companies. However, it must be stressed that Danform in all other aspects is an independent firm with its own production leader and quality responsible.

4.4.2 The process from order receiving to production hall

4.4.2.1 From order receiving to production planning and control system

The order department connects daily to the ECIS-system, from which drawings are transferred to the database at the supplier. The date when the order must be produced, the production date, is automatically set in the database according to order delivery date. Drawings are printed and checked through a manual 3-person control system. The first person prints the drawing and compares it with the order in the ECIS-system. If no information is missing and order and drawing correspond, an order confirmation is sent to IKEA. The second person compares the drawing with the saved drawing information in the supplier database, and creates the production paper in the supplier's order receiving system. The third person performs a last control, by comparing the drawing with the production paper in the order receiving system. If all corresponds, the order is transferred to the PPC system. The order process is described in detail in Appendix 1.

If any information is incorrect, insufficient or changed throughout the order process, a call back is made to an IKEA department store or a navigator. A navigator is an IKEA employee, working with business support. There is no upper time limit of when a call back must be made, nor is there a time limit of when the IKEA department store or the navigator must reply. Until the supplier has received an answer, the order is put on hold.

4.4.2.2 From production planning and control system to production hall

The supplier's PPC system is point based, where each worktop is given a number of points according to its complexity. According to the point system, a more complex worktop means that it must be processed at more work stations, resulting in additional cycle time and transport time. The more complex the worktop is, the more points are appointed to it. The point system is used to estimate production capacity. Orders are optimized according to the PPC system, making it possible to release orders to production as early as needed.

4.4.3 The manufacturing system

4.4.3.1 Production hall

The supplier has one production hall where laminate worktops are processed. The production hall is almost completely automatic, and worktops are mostly transported between work stations on conveyer belts. The PPC system handles the optimization and monitoring of the production flows.

Figure 4-11 illustrates the layout of the production hall. One work station where wall panels are processed has been removed. The automatic machines are located on the left side of the wall, whereas most of the manual work stations are located on the right side. The process of each work station is explained in Appendix 2.

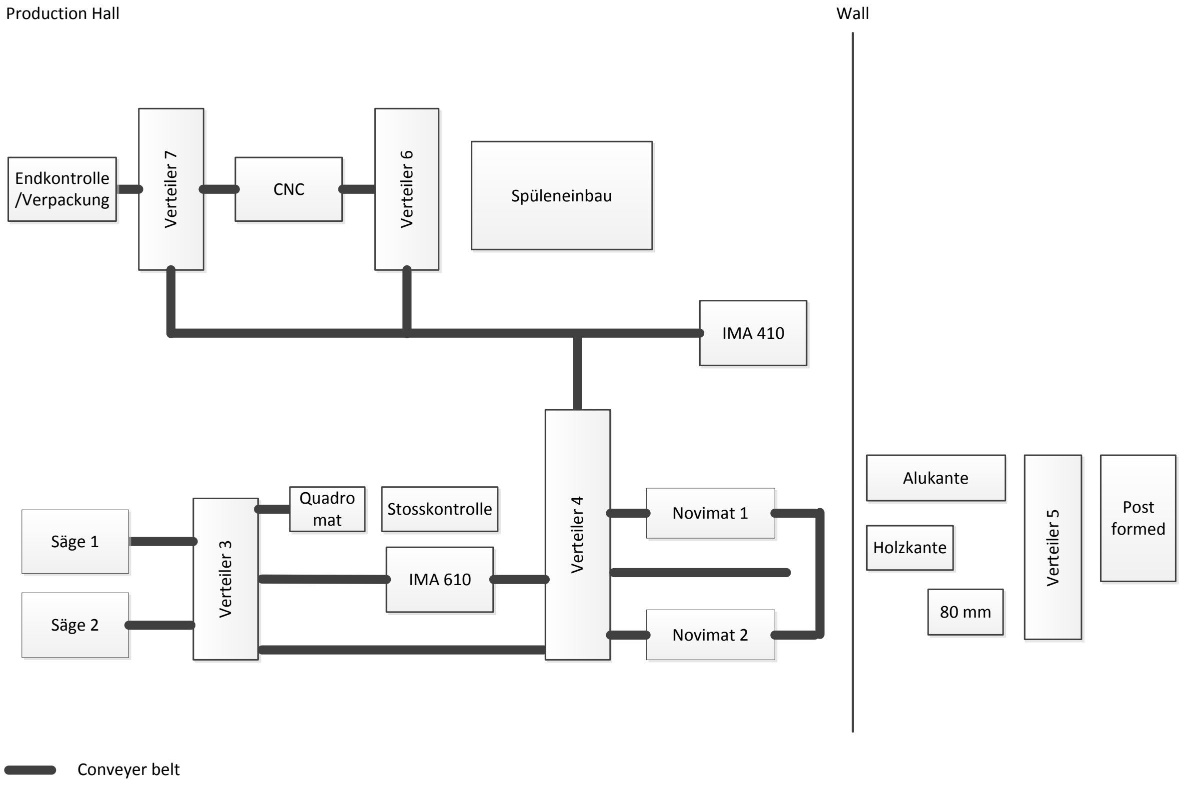


Figure 4-11: Layout of Danform production hall (Möller & Sahleström, 2011).

4.4.3.2 Production flows

The production hall at the supplier is a single-unit manufacturing system with a large production volume. The manufacturing layout of the production hall is a function oriented line production, where most machines are arranged in the processing order for a certain product. Most of the material handling and transportation are automatic with automatic buffers between the work stations. Figure 4-12 illustrates the production flows at the supplier, showing a main flow combined with a circular sub-flow. The circular sub flow contains all stations performing gluing of edges, where gluing of PP or laminate edges is the last stage. Once gluing of edges is performed, the worktop will be put back in a buffer, awaiting further transportation.

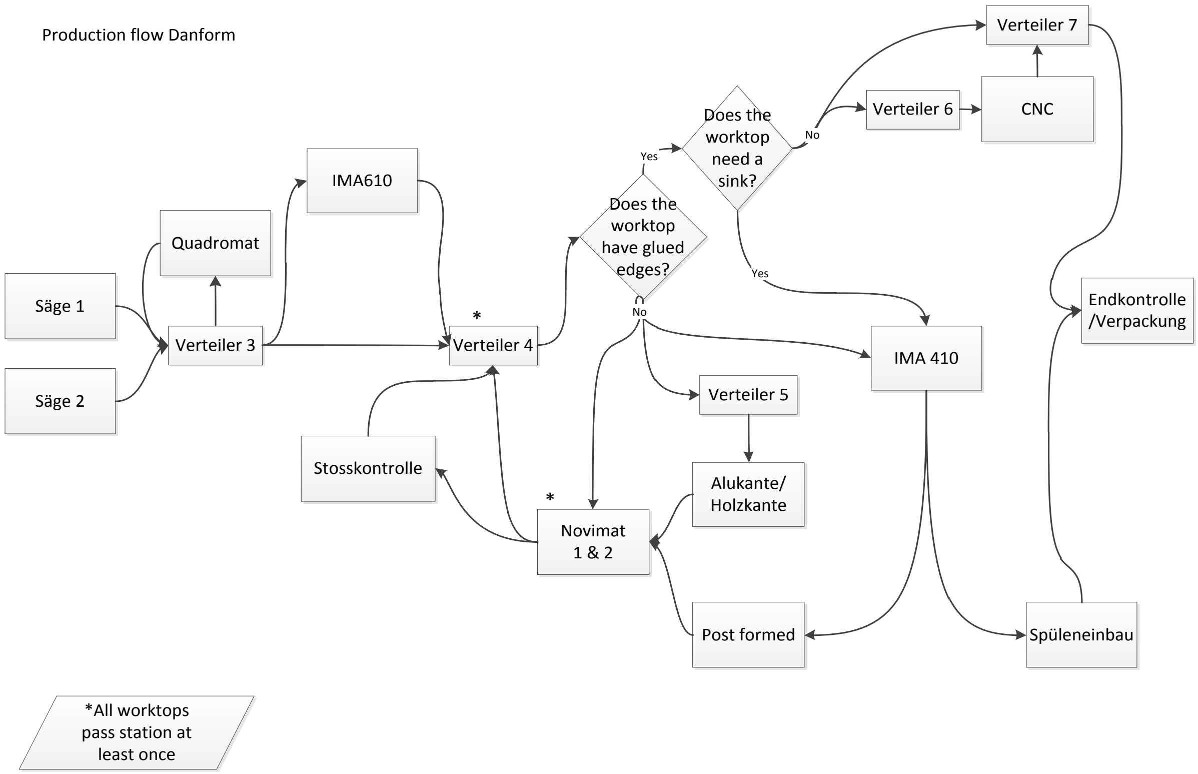


Figure 4-12: Production flows in Danform production hall (Möller & Sahleström, 2011).

4.4.4 Measurement system

The measurement system at the supplier is used to document rejections. When a rejection is detected, the operator should reflect and decide about the following information, which is later to be given to the production leader, who will type the data into the measurement system:

1. The operator reflects and decides which category the rejection belongs to; manufacturing error, damage error, error caused by order department, error caused by sub-supplier or general error.
2. The operator chooses a sub-category for the first choice, which gives more detailed information about the rejection. Sub-categories consist of a mixture of quality parameters and rejection causes. However, a sub-category can not be chosen for a rejection caused by the order department.
3. The operator writes down at which station the rejection was detected.

The supplier neither has documentation of how to report rejections to the production leader, nor have these instructions been specifically explained to the operators.

4.4.5 Quality related departments

The supplier has two departments, which are directly linked to quality work. These are described below.

4.4.5.1 Quality department

The quality department consists of a person acting as the quality responsible, who has been employed around 6 months. Former quality work was performed by the production manager, but since this person only spent two days a week at Danform facilities, this work arrangement was decided as unsustainable. The quality department has not set any clear goals, but is currently working with three KPI parameters: Lowering the rejection rate, lowering the claim rate and lowering the use of energy. The current work involves performing internal evaluations, process measurements and follow-ups. The supplier’s plan for the future is to evaluate these KPI parameters within a monthly time frame for better understanding of the quality level and the quality work performance.

The quality department handles the maintenance of the binder at each manufacturing work station, which contains work descriptions, maintenance plans and suggestion improvement papers. Suggestions from operators regarding the manufacturing are given to the quality responsible and are directly discussed. If the suggestion appears promising, it is approved by the quality responsible and implemented when feasible.

The quality department also performs monthly TÜV-reports, which is a maintenance and security follow-up of all work stations, where their reliability is assessed.

IKEA documentation is not handled by the quality department, but by the management assistant, who handles the receiving, storing and updating. The quality responsible states the communication regarding IKEA product documentation to be inexistent.

4.4.5.2 Purchasing department

The purchasing department handles quality work within purchasing and claims. The department performs evaluation of sub-suppliers based on two criteria: Error rate in delivery, based on correct amount of delivered parts, and delivery time, based on the on-time delivery rate. Evaluations are saved for in-house use, and are not sent to sub-suppliers.

The department receives manufacturing measurements of rejections caused by sub-suppliers. This information is reviewed every two weeks and sent to the sub-suppliers, together with purchase price and agreed deduction of already performed work steps. The department conducts no further follow up of the sub-supplier causes and does not include this in the sub-supplier evaluation.

The department also handles customer claims, which are received directly from IKEA. The department decides whether or not to accept the claim, by determining if the claim cause originated from the supplier. If the claim is accepted, it is registered in the annual claim assessment document. The claim statistic is shared with the quality department.

4.4.6 The Quality Management System

Danielmeyer developed a quality management handbook in 2001, with a similar structure as ISO 9000. The management handbook was then adapted to better fit the Danform structure. The handbook consists of six major parts where the following information is stated.

- ***About Danform***

The supplier states that the company will serve IKEA with a customer perspective, always striving to fulfill IKEA IWAY and IKEA quality requirements. The supplier has a coworker perspective, where success of quality is related to the responsibility of each employee; each individual is responsible for the result of his own work. The foundation is based on leadership, education and training of coworkers, where the CEO is responsible for the management system. According to the management system, quality improvements mean to secure processes, avoiding reiteration of mistakes and failures and not authorizing cost saving sanctions to affect the quality level.

- ***The management system***

The supplier’s management system shall have influence on all supplier processes in order to fulfill customer requirements and industrial safety. It is aligned with IKEA IWAY and is based upon the foundations of ISO 9001 and ISO 14001. The management handbook is essential to use in the everyday work and must be adapted to new IKEA requirements, new customers as well as the affected surroundings.

- ***The management responsibility***

The management should succeed with the improvement and development of the management system. This is done by:

- Communicating the importance of obtaining customer, environmental and safety requirements.
- Establishing business policy and objectives. The business policy includes cooperation with customers in order to solve problems, as well as being a trustful partner who stands for quality, flexibility and a fair price. The coworkers must feel responsibility for their own work and must be supported concerning training and guidance. The supplier must also strive to minimize the environmental impact.
- Involving work standards according to IKEA IWAY and product quality aspects according to IKEA product requirements.
- Implementing and conducting management reviews.
- Allocating needed resources.

The supplier goals are derived from the business policy and must be quantifiable. The goals are presented below; however not in order of priority:

1. Increase customer satisfaction.
2. Increase coworker satisfaction.
3. Expansion of market share.
4. Continuous improvements within all departments.
5. Reduce energy usage.
6. Decrease use of raw material.
7. Lowering wastage.
8. Reduction of emissions.
9. Decrease number of sickness-related days.
10. Minimizing of industrial accidents.
11. Minimize negative health effects of coworkers.
12. Optimizing of processes.

The management has declared a person responsible for the execution and documentation of the management handbook. A monthly management review is to be performed by the management and the handbook responsible, where supplier goals are to be discussed and evaluated.

- ***The management of resources***

Resources need to be provided in order to execute the described actions in the management handbook. Human resources are of importance as well as the communication of quality issues and goals to operators, explaining their part in the fulfilling of customer requirements and encouraging suggestions for improvements.

- ***Production realization***

A production process must be planed, including describing the process with a process owner, process goals and documents in place. Process goals need to be established based upon the following factors:

- Stated product requirements.
- All other requirements necessary to obtain product perfection.
- Legal, environmental and safety requirements.

Improvement of the production will be based upon internal suggestions and customer requirements. Certain documents are to be used to steer production realization with focus on equipment, work environment, the usage of measuring tools, monitoring of the production as well as securing outgoing goods.

- ***Measurements, analysis and improvements***

Certain operations, in order to monitor, measure, analyze and improve processes and products, have been planned and are executed. This is to secure the link between the management system and products, processes and requirements. The monitoring and measuring of processes are conducted throughout the production processes, including production, logistics and purchasing as well as their impact on environment and safety. The measurement metrics are stated in the process documentation and the process owner allocates the responsibility. All employees are part of the improvement process.

It is important to detect and segregate non-conforming products. Investigations and analyses regarding customer satisfaction, process performances, supplier evaluation, the management system as well as the process of continuous improvements must be executed.

Internal audits are planned and executed on a regular basis, and the results are used for improving the management system as well as processes and products. Audits contain investigations in order to assess if the supplier is obtaining the requirements regarding quality, environment and safety.

4.4.7 Quality control

4.4.7.1 Product quality control within the manufacturing

The work descriptions at each work station include specific work station related tasks and a general quality instruction. The specific work station related tasks include a check-list of what operations to perform, as well as in which order. If specific control tasks are to be executed as part of the operation, this is also stated.

The general quality instructions are identical at each station, which states that 2-3 worktops per station and shift are to be thoroughly controlled. Criteria, requirements and inspection devices are stated within the following aspects:

- Dimensional and joint stability.
- Compactness of edges and glue.
- Quality of surface.

The supplier describes its product quality control approach, that by controlling worktops upstream the production flow, rejections will be detected at an earlier stage. This is done through work descriptions as well as giving each operator individual responsibility of process execution. Therefore, the supplier has determined that it is unnecessary for the final control to scrutinize each worktop.

4.4.7.2 Process control within the manufacturing

The work descriptions contain mapped and documented manufacturing processes. Process control is also performed by documenting measurements of tolerances at machine processes. Operators perform and document process control at the following work stations, and the documented process control is collected by the quality department once a week:

- **Säge 1 & 2** – Control of length and depth of 5 worktops per shift, by using measuring tape. Tolerances are ± 2 mm.
- **Novimat 1 & 2** – Performance of knife tests on PP-edges twice per shift, where a knife is used to tear off a recently glued PP-edge from a worktop. A visual control is performed by viewing if chips are stuck on the edge, acting as a performance indicator of the glue process. If no chips are stuck on the edge, the machine must be adjusted.
- **IMA 410** – Control of depth of the joint on every worktop when joint is milled, by using a dial gauge. Tolerances are ± 0,2 mm.
- **IMA 610** – Control of depth of the joint on every worktop when joint is milled, by using a dial gauge. Tolerances are ± 0,2 mm.
- **CNC** – Control of depth of the joint on every worktop, by using a dial gauge. Tolerances are ± 0,2 mm. Control of depth of groove on every worktop, by using a groove template. Lower tolerance limit is set by template, whereas no upper tolerance limit exists. Control of joint is also performed by using templates for joints on random chosen worktops, which is not documented.
- **Spüleneinbau** – Performance of vacuum test on every built-in sink, by putting a frame on the sink and measuring the pressure drop in order to control the glue density. Tolerances are -3 Pa.

5 Modification and application of manufacturing frameworks

In this chapter, modification and application of manufacturing frameworks are presented. The implementations were performed to better suit both IKEA and the suppliers.

5.1 CBD model

The theoretical framework of the CBD model was used in two different approaches. Firstly, the CBD model was used as a single unit approach, according to chapter 5.1.3. Secondly, it was used as a system approach, according to chapter 5.1.4. The single unit approach is more complex and returns the exact manufacturing cost for a chosen worktop, used for calculating the cost structure. The system approach returns an average manufacturing cost for the average worktop, used for calculating the economic effect of root-cause preventions. Both approaches will display the manufacturing cost of the worktops produced at each supplier during the time frames of the PPM measurements, described in chapter 5.2.1

5.1.1 Adjusting of formula and introducing of new parameters

During the implementation of the CBD model, new parameters were introduced to fit both IKEA and the suppliers. The use of parameters differs for each supplier, depending on the manufacturing system.

The production rate, q_p, was determined as not possible to define since each product within each manufacturing system is unique. Therefore, the production rate will be set to zero in the CBD model.

Since none of the suppliers are measuring the downtime ratio, q_s, an estimation of the parameter was performed. Equation 5-1 was created from *Equation 3-9,* by viewing the production time as a time window, $T_{P,\, tw}$. A time window equals a time period of e.g. a day, a week or a month, where i=1…n is the number of time windows taken into the calculations. In Equation 5-1, the time window chosen equals the total production time and the amount of worktops produced within the time window, $N_{0,\, tw}$, constitutes the batch size. The cycle time, $\bar{t}_0$, and the setup time, $\bar{t}_{SU}$, were set as average values. The maximum downtime ratio, $q_{s,\, max}$, can then be solved from the equation. The maximum downtime ratio must be used carefully since it also includes the production rate loss and the degree of utilization. In this master thesis, the value $q_{s,\, max}$ will be used to perform a valid estimation of the downtime ratio.

$$T_{Pb} = T_{p,tw_{i=1}} = \frac{N_{0,tw}\bar{t}_{SU}}{1-q_{S,SU}} + \frac{N_{0,tw}\bar{t}_0}{(1-q_Q)(1-q_S)(1-q_P)}\Big|_{max}$$ **Equation 5-1**

The parameter **q_{RW}** was introduced to simulate the rate of re-work in the manufacturing system. Re-work occurs when the processing of a worktop does not meet the quality standards, however can be re-processed at the same or a different station. The parameter is defined as the number of parts that are re-worked divided by the nominal batch size and the number of re-worked parts.

$$q_{RW} = \frac{N_{re-work}}{N_0 + N_{re-work}}$$ **Equation 5-2**

The parameter $\mathbf{q_{RU}}$ was introduced to simulate the number of worktops that were rejected, but which material could be re-used. This parameter is similar to the rejection rate, but will not affect the material cost. The definition of the parameter is the number of parts which can be re-used divided by the batch size.

$$q_{RU} = \frac{N_{re-use}}{N_0} \qquad \textit{Equation 5-3}$$

In order to view the effect that the cost of claims has on a worktop a few new parameters have to be introduced. The parameter $\mathbf{q_{CL}}$ equals the percentage of claimed worktops and is defined as the number of claimed parts divided by the batch size.

$$q_{CL} = \frac{N_{claims}}{N_0} \qquad \textit{Equation 5-4}$$

A **cost term e** was created describing the claim penalty cost per part. It is defined as the penalty cost per claim, k_{CL}, multiplied by the amount of placed orders within the time window, $N_{orders,tw}$, and the percentage of claimed orders, $q_{CL\%}$, which is evenly distributed over the batch size within the time window. The average correlation between q_{CL} and $q_{CL\%}$ is 2,5.

$$\left[\frac{k_{CL}(N_{orders,tw}q_{CL\%})}{N_{0,tw}}\right]_e \qquad \textit{Equation 5-5}$$

5.1.2 CBD model presentation

The adjusted CBD model with new parameters is presented in Equation 5-6 with new introduced parameters in bold.

$$\begin{aligned}
&k = \\
&\frac{k_A}{N_0}\left[\frac{1}{n_{PA}}\right]_a + \frac{k_B}{N_0}\left[\frac{N_0}{(1-q_Q)(1-q_B)(1-\boldsymbol{q_{CL}})}\right]_b + \\
&\frac{k_{CP}}{60N_0}\left[\frac{t_0N_0}{(1-q_Q)(1-q_P)(1-\boldsymbol{q_{RW}})(1-\boldsymbol{q_{RU}})(1-\boldsymbol{q_{CL}})}\right]_{c1} + \\
&\frac{k_{CS}}{60N_0}\left[\frac{t_0N_0}{(1-q_Q)(1-q_P)(1-\boldsymbol{q_{RW}})(1-\boldsymbol{q_{RU}})(1-\boldsymbol{q_{CL}})}\frac{q_S}{(1-q_S)} + T_{SU} + \right. \\
&\left.\frac{1-U_{RB}}{U_{RB}}T_{Pb}\right]_{c2} + \frac{k_D}{60N_0}\left[\frac{t_0N_0}{(1-q_Q)(1-q_P)(1-q_S)(1-\boldsymbol{q_{RW}})(1-\boldsymbol{q_{RU}})(1-\boldsymbol{q_{CL}})} + \right. \\
&\left. T_{SU} + \frac{1-U_{RB}}{U_{RB}}T_{Pb}\right]_d + \left[\frac{\boldsymbol{k_{CL}N_{orders,tw}q_{CL\%}}}{\boldsymbol{N_{0,tw}}}\right]_e
\end{aligned} \qquad \textit{Equation 5-6}$$

5.1.3 CBD model implementation as a single unit approach

The program used in the implementation of the CBD model as a single unit approach was Microsoft Excel, since this software is well used within IKEA and at both suppliers and the model could therefore be used in the future.

The CBD model as a single unit approach will calculate the cost of the batch size as $N_0 = 1$ and regards each work station as a planning point. Depending on the variables chosen by the customer, the worktop will follow a certain production flow in each supplier's manufacturing system. The worktop will then carry the manufacturing cost for the work stations in which it has been refined. Changes in variables can also result in changed material and wage costs.

The implementation of the CBD model involved programming in Microsoft Excel, where production flows are dependent on material, worktop size, shapes, edges, sinks, pre-milled surfaces and joints. Two specific implementations were constructed, one for each supplier.

A certain production flow has a number of refinement processes, i = 1, 2…, n-1, n. At the first refinement process, the material cost, k_B, equals the purchase price and the transportation costs. In sequent processes, the material cost is calculated as the output cost of the previous station, according to Figure 5-1.

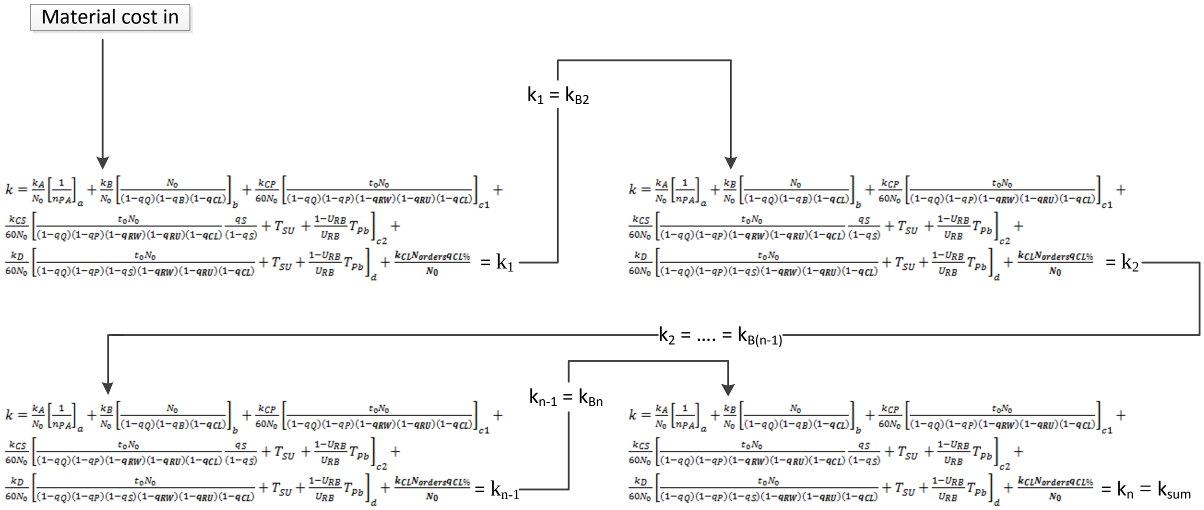
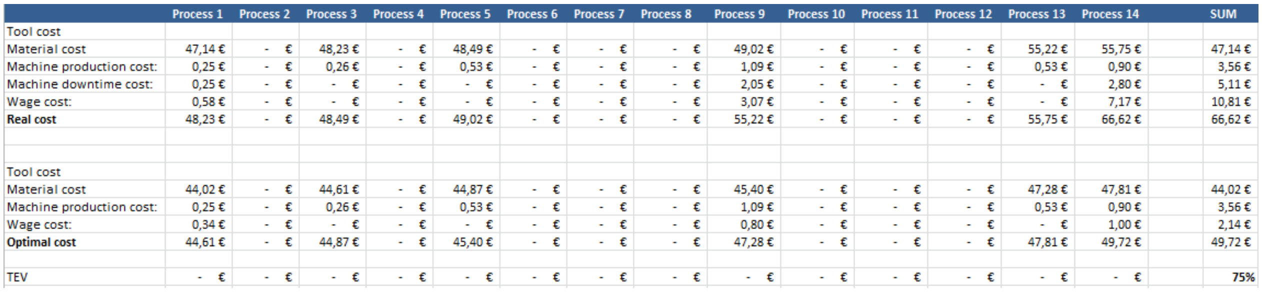


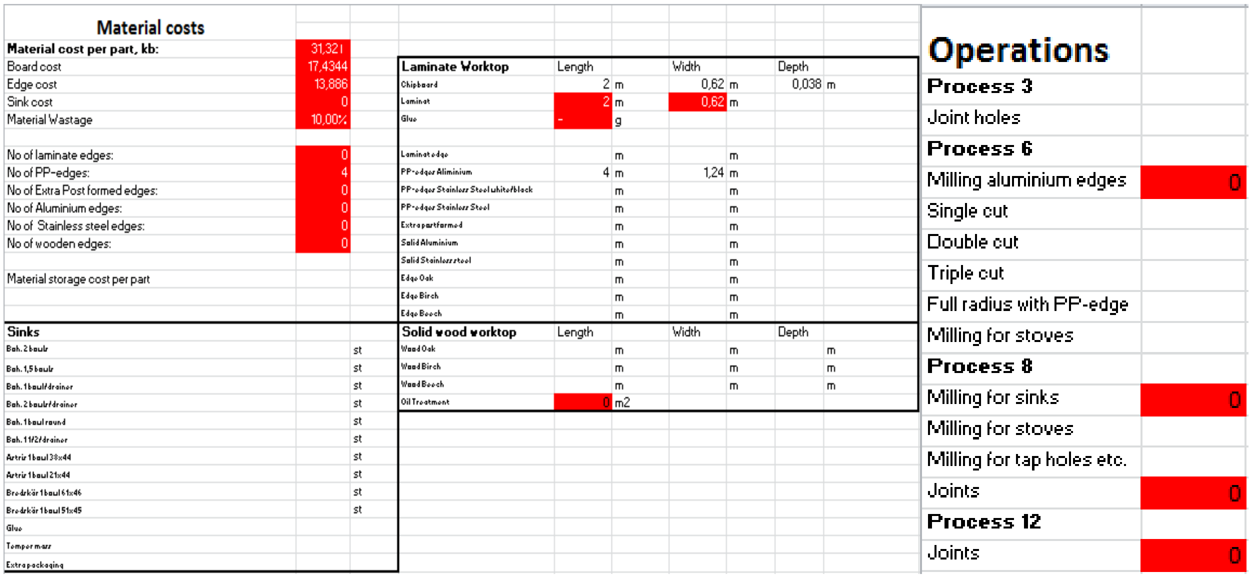
Figure 5-1: A scheme of cost calculation (Möller & Sahleström, 2011).

Figure 5-2 shows the main calculation sheet for one of the suppliers, summarizing the cost of all processes. A process in the production is either activated by choosing material or operations, shown in Figure 5-3. Once a process is activated, the cost parameters and cost terms will be calculated in a supporting sheet and added to the summarized cost in the main calculation sheet.



	Process 1	Process 2	Process 3	Process 4	Process 5	Process 6	Process 7	Process 8	Process 9	Process 10	Process 11	Process 12	Process 13	Process 14		SUM
Tool cost																
Material cost	47,14 €	- €	48,23 €	- €	48,49 €	- €	- €	- €	49,02 €	- €	- €	- €	55,22 €	55,75 €		47,14 €
Machine production cost:	0,25 €	- €	0,26 €	- €	0,53 €	- €	- €	- €	1,09 €	- €	- €	- €	0,53 €	0,90 €		3,56 €
Machine downtime cost:	0,25 €	- €	- €	- €	- €	- €	- €	- €	2,05 €	- €	- €	- €	- €	2,80 €		5,11 €
Wage cost:	0,58 €	- €	- €	- €	- €	- €	- €	- €	3,07 €	- €	- €	- €	- €	7,17 €		10,81 €
Real cost	48,23 €	- €	48,49 €	- €	49,02 €	- €	- €	- €	55,22 €	- €	- €	- €	55,75 €	66,62 €		66,62 €
Tool cost																
Material cost	44,02 €	- €	44,61 €	- €	44,87 €	- €	- €	- €	45,40 €	- €	- €	- €	47,28 €	47,81 €		44,02 €
Machine production cost:	0,25 €	- €	0,26 €	- €	0,53 €	- €	- €	- €	1,09 €	- €	- €	- €	0,53 €	0,90 €		3,56 €
Wage cost:	0,34 €	- €	- €	- €	- €	- €	- €	- €	0,80 €	- €	- €	- €	- €	1,00 €		2,14 €
Optimal cost	44,61 €	- €	44,87 €	- €	45,40 €	- €	- €	- €	47,28 €	- €	- €	- €	47,81 €	49,72 €		49,72 €
TEV	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €		75%

Figure 5-2: Microsoft Excel implementation of summarized sheets (Möller & Sahleström, 2011).



Material costs

Material cost per part, kb:	31,321	
Board cost	17,4344	
Edge cost	13,886	
Sink cost	0	
Material Wastage	10,00%	
No of laminate edges:	0	
No of PP-edges:	4	
No of Extra Post formed edges:	0	
No of Aluminium edges:	0	
No of Stainless steel edges:	0	
No of wooden edges:	0	
Material storage cost per part		
Sinks		
Boh. 2 bowls		st
Boh. 1,5 bowls		st
Boh. 1 bowl/drainer		st
Boh. 2 bowls/drainer		st
Boh. 1 bowl round		st
Boh. 1 1/2/drainer		st
Artris 1 bowl 38x44		st
Artris 1 bowl 21x44		st
Bredskär 1 bowl 61x46		st
Bredskär 1 bowl 51x45		st
Glue		
Temper mass		
Extra packaging		

Laminate Worktop	Length		Width		Depth	
Chipboard	2	m	0,62	m	0,038	m
Laminat	2	m	0,62	m		
Glue	-	g				
Laminat edge		m		m		
PP-edges Aliminium	4	m	1,24	m		
PP-edges Stainless Steel white/black		m		m		
PP-edges Stainless Steel		m		m		
Extra postformed		m		m		
Solid Aluminium		m		m		
Solid Stainless steel		m		m		
Edge Oak		m		m		
Edge Birch		m		m		
Edge Beech		m		m		
Solid wood worktop	Length		Width		Depth	
Wood Oak		m		m		m
Wood Birch		m		m		m
Wood Beech		m		m		m
Oil Treatment	0	m2				

Operations	
Process 3	
Joint holes	
Process 6	
Milling aluminium edges	0
Single cut	
Double cut	
Triple cut	
Full radius with PP-edge	
Milling for stoves	
Process 8	
Milling for sinks	0
Milling for stoves	
Milling for tap holes etc.	
Joints	0
Process 12	
Joints	0

Figure 5-3: Microsoft Excel implementation of material and operations (Möller & Sahleström, 2011).

In order to obtain a general representation of laminate worktops within the PERSONLIG range, the following four worktops were chosen to be calculated. Through observations at the supplier facilities, the thesis authors consider these four worktops to represent more common chosen variables by customers, enabling comparisons of a larger representation within the PERSONLIG range.

- 2000 mm length, 620 mm depth, 38 mm height, 4 PP-edges.
- 2000 mm length, 620 mm depth, 38 mm height, 1 aluminium edge, 3 PP-edges, 1 joint.
- 2000 mm length, 620 mm depth, 38 mm height, 4 PP-edges, 1 Boholmen sink with 2 bowls.
- 2000 mm length, 620 mm depth, 38 mm height, 1 extra post formed edge, 3 PP-edges, 1 stove.

For solid wood worktops, three different birch worktops were chosen to be calculated in order to view the impact of different refinement process on the cost structure for a specific wood material.

- 2000 mm length, 620 mm depth, 38 mm height.
- 2000 mm length, 620 mm depth, 38 mm height, 1 joint, 1 stove.
- 2000 mm length, 620 mm depth, 38 mm height, 1 Boholmen sink with 2 bowls.

5.1.4 CBD model implementation as a system approach

The program used in the implementation of the CBD model of a system approach was Microsoft Excel.

The CBD model as a system approach views the manufacturing system as a control volume within a time window, shown in Figure 5-4. The manufacturing system is regarded as a planning point where the batch size is $N_0 = N_{0,\,tw}$, cycle time is $t_0 = \overline{t_0}$ and the setup time is $T_{SU} = N_{0,\,tw}\,\overline{t_{SU}}$. The manufacturing costs for all work stations will be divided on all worktops. Two specific implementations were constructed, one for each supplier.

The amount of worktops in the control volume is considered constant.

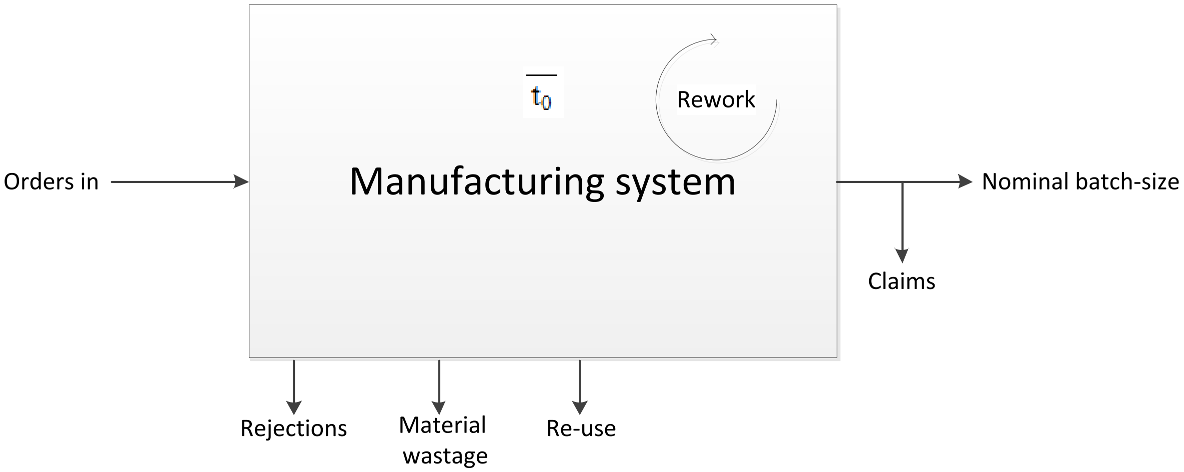


Figure 5-4: Manufacturing system with quality parameters viewed as a control volume (Möller & Sahleström, 2011).

5.2 PPM

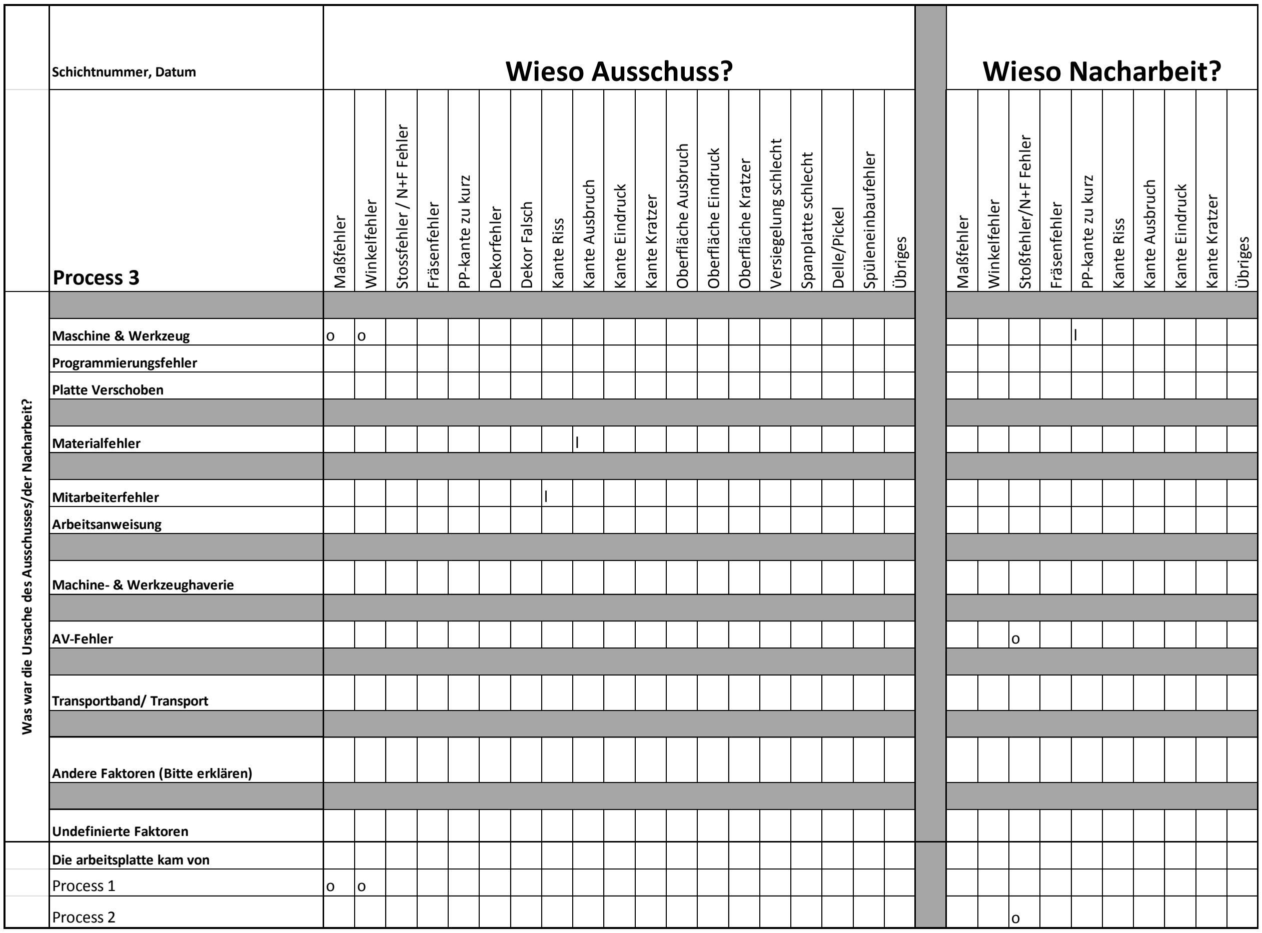
The parameters chosen to be measured in the PPM were the rejection rate, q_Q, rate of re-work, q_{RW}, and the rate of re-use, q_{RU}. Neither production rate nor downtime was possible to measure, since neither manufacturing system supported the measuring of these parameters.

5.2.1 Development of PPM forms

The PPM concept was further developed by the thesis authors in order to obtain as much information from the production halls as possible. An example of a PPM form can be seen in Figure 5-5.

- The PPM forms were created to capture the manufacturing performance of work stations over time, by using one sheet per shift and day. The thesis authors consider performance over time to be a good tool for the distinction between chronic and temporary problems.
- The forms were constructed to determine if the rejected part was found before or after processing at a certain station. The operators were to put an “o” in the PPM forms if the rejected part was found before the work station and an “l” if the rejected part was found during or after processing. When putting an “o” in the PPM forms, the operators were instructed to put a second “o” furthest down in the PPM forms, showing the precedent work station.
- For further ensuring of correct PPM measurement execution, an instruction paper was created concisely explaining the reason for the PPM forms and how to fill them out.

The use of the PPM concept was thoroughly discussed with both suppliers. The PPM forms were agreed to be filled out by the operators at each work station. The identification of quality parameters and factors were discussed with the suppliers and taken from their measurement systems. The measurement of rejection, re-work and re-use was adapted to each work station at each supplier. The time frame of the PPM measurements was agreed to be two weeks at Lechner and three weeks at Danform.



	Schichtnummer, Datum	Wieso Ausschuss?																				Wieso Nacharbeit?									
	Process 3	Maßfehler	Winkelfehler	Stossfehler / N+F Fehler	Fräsenfehler	PP-kante zu kurz	Dekorfehler	Dekor Falsch	Kante Riss	Kante Ausbruch	Kante Eindruck	Kante Kratzer	Oberfläche Ausbruch	Oberfläche Eindruck	Oberfläche Kratzer	Versiegelung schlecht	Spanplatte schlecht	Delle/Pickel	Spüleneinbaufehler	Übriges		Maßfehler	Winkelfehler	Stoßfehler/N+F Fehler	Fräsenfehler	PP-kante zu kurz	Kante Riss	Kante Ausbruch	Kante Eindruck	Kante Kratzer	Übriges
Was war die Ursache des Ausschusses/der Nacharbeit?																															
	Maschine & Werkzeug	o	o																							l					
	Programmierungsfehler																														
	Platte Verschoben																														
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	Andere Faktoren (Bitte erklären)																														
	Undefinierte Faktoren																														
	Die arbeitsplatte kam von																														
	Process 1	o	o																												
	Process 2																							o							

Figure 5-5: Example of a PPM form at a certain station (Möller & Sahleström, 2011).

5.2.2 Implementation of PPM at Lechner

The implementation of the PPM forms at the supplier was performed by supplier personnel. This was decided due to the geographical distance. At the intended time of the PPM measurements, unplanned changes had to be made in the production flows due to changes in the PERSONLIG range. This resulted in the supplier performing the PPM measurements without notifying the thesis authors, which ruled out the possibility of follow-ups. Unfortunately, two changes in the PPM concept were made by the supplier;

- The responsibility of filling out the PPM forms was put at shift leader level instead of operator level. This was due to the fact that the supplier regarded an implementation at operator level as not possible. This is estimated of having certain effects on the results, since it limits the operators' possibility to discuss rejection and rejection causes, further discussed in chapter 6.1.1.
- The amount of forms per station was reduced to one form per week. This is estimated of having limited effects on the results.

5.2.3 Implementation of PPM at Danform

The implementation at the supplier was performed according to the development of the PPM forms, explained in chapter 5.2.1. The thesis authors explained at each work station how the operators were to fill out the PPM forms. A follow-up was performed after half of the measuring time and further discussed with operators.

6 Analysis

In this chapter, the information gathered throughout the master thesis is analyzed, combining the three preceding chapters. The results of the measurements are described, analyzed in combination with interviews and observations, assessing the supplier's quality work performance.

6.1 Lechner

6.1.1 PPM Measurement analysis

The PPM measurements at the supplier were conducted during week 44-45, 2011. The results are presented and discussed in this chapter. The analysis is divided into production hall and worktop material. The PPM measurements from two work stations in production hall 1 were lost before reaching the thesis authors. Due to the loss of measurements, an increase of the rejection rate from 1.2 % to 1.4 % was decided together with expertise from supplier personnel.

The left axis of Figure 6-1 illustrates the amount of produced worktops per material and production hall, whereas the right axis demonstrates the rejection rate. 5917 worktops started its production in Hall 5, from which 3524 worktops were controlled and delivered. This implies that 2393 worktops were transported to production hall 1 for further refinement. The batch size in Figure 6-1 therefore shows the input of worktops of each manufacturing system, and not the actual produced volume.

During the measurement period, the rejection rate of laminate worktops in Hall 1 was lower than the average rejection rate, which according to supplier personnel, during normal production circumstances, varies between 2.0-2.5 %. Figure 6-1 indicates no correlation between the amount of produced worktops and rejection rate, a conclusion supported by experience from supplier personnel.

The re-work registered in the PPM measurements show a rate of re-work of 0,26 %, whereas 72 % of the re-work causes was considered to be “Maschine & Werkzeug”. The amount of re-use registered corresponded to a fraction of the registered rejections, thus not further investigated.

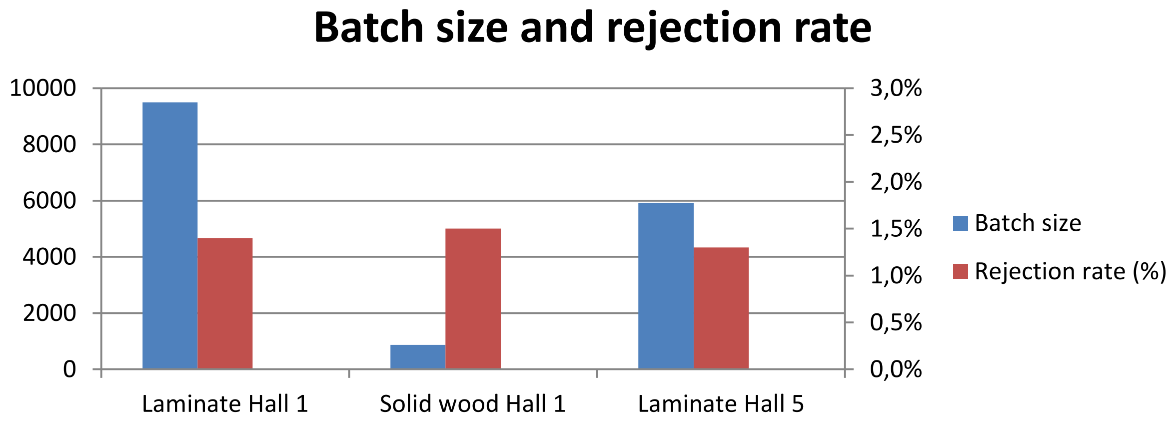

Figure 6-1: Batch size and rejection rate (Möller & Sahleström, 2011).

6.1.1.1 Laminate worktops in Hall 1

Figure 6-2 shows the amount of rejections for each quality parameter in production hall 1. As seen in the figure, no specific quality parameter can be considered more frequent than others. However, 78 % of the rejections can be categorized into three major groups:

- Dimensional errors, 16 %.
- Visual damages on surfaces and edges, 43 %.
- Visual errors in laminate, 19 %.

The quality parameter categorized as "Übriges" could not be verified since the shift leaders were not able to go into details for specific work stations.

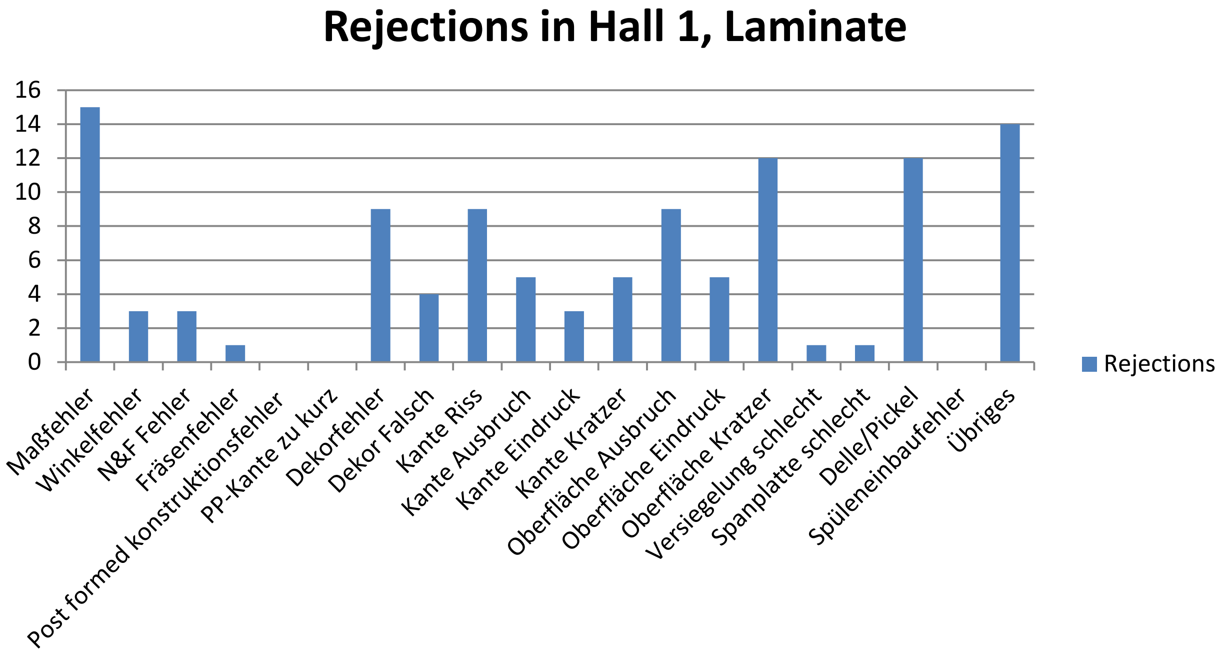

Figure 6-2: Rejections of laminate worktops in Hall 1 (Möller & Sahleström, 2011).

Figure 6-3 demonstrates the rejection causes for laminate worktops in production hall 1. 63 % of the rejections were considered to be caused by "Maschine & Werkzeug" and 28 % by "Materialfehler". Due to the complexity of the production and the fact that no causes were considered as unknown, further discussions of the results were held with the shift leaders regarding the possibility of determining 100 % of the rejection causes, without using any unknown factors. The response indicated the possibility to determine the actual cause in almost every case. However, some causes registered as "Maschine & Werkzeug" should actually have been selected as "Undefinierte Faktoren".

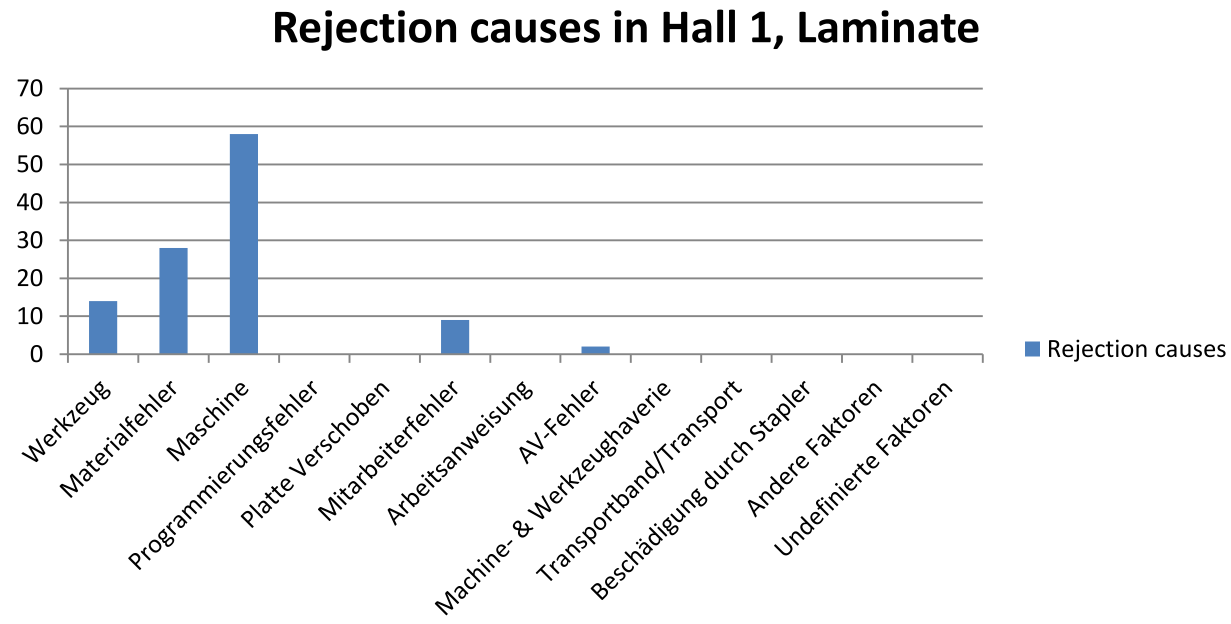

Figure 6-3: Rejection causes of laminate worktops in Hall 1 (Möller & Sahleström, 2011).

Figure 6-4 illustrates the number of rejections and the rejection rate at each work station of laminate worktops in hall 1. “BIMA P480” and “Endkontrolle Spüle” have no registered rejections since the results from these work stations were lost. However, the result from the PPM measurements proved that 82 % of all rejections were detected before the worktop was processed.

The final control had the highest number of rejections, however due to the large amount of processed worktops at this work station, it corresponded in the third lowest rejection rate. Among the work stations with more than 2000 processed worktops, the highest rejection rate was 0.5 %. This indicates that work stations with shorter average cycle times have lower rejection rates. E.g. “BIMA 610” and “Endkontrolle” are two stations in the latter part of the production flow, whereas the rejection rate at “BIMA 610” before processing amounts to 0,97 % and at “Endkontrolle” to 0,39 %. Taken into account that a large majority of rejections were detected before being processed, in combination with the complexity of the production flows illustrated in Figure 4-8, the differences of rejection rates between work stations should statistically not differ this much. Currently, the number of detected rejections at certain work stations is more dependent on product quality control before processing. This implies that values for each work station in Figure 6-4 are more connected to the detection rate than to the performance of the refinement process at the same work station.

Further investigation of these findings was planned to be performed after the PPM measurement analysis, starting from the final inspection, following different flows upstream in the production flows, interviewing operators at each station and discussing the result. Unfortunately, this approach was abandoned due to one major reason. The operators were not the ones conducting the PPM measurements and had not been informed about the PPM data collection. As a result, the discussions regarding specific rejection causes could not be carried out; since the common response was that “everything can happen everywhere”.

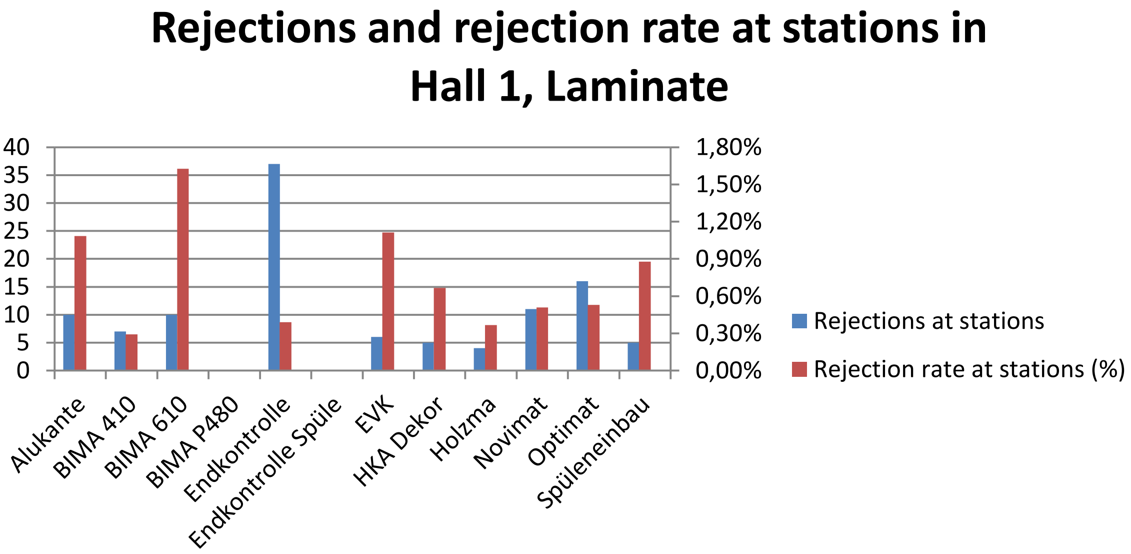

Figure 6-4: Rejections and rejection rate at stations in hall 1, Laminate (Möller & Sahleström, 2011).

6.1.1.2 Solid wood worktops in Hall 1

The rejections of solid wood worktops in production hall 1 amounted to 13 parts, corresponding to a rejection rate of 1,5 %. The rejection rate is on a similar level as laminate worktops. 69 % of the rejections were detected before being processed, and 69 % of the rejection causes were considered to be “Maschine & Werkzeug”.

In Figure 6-5, the rejections of solid wood worktops in production hall 1 are shown. The possibilities to perform re-work on edges and surfaces should be noted, explaining the absence of reported visual damages. Thus, re-work is part of the refinement process at “Massivholz HB” and measuring this showed to be difficult. Also, due to the low number of rejections considered as “Übriges”, this quality parameter could not be further investigated.

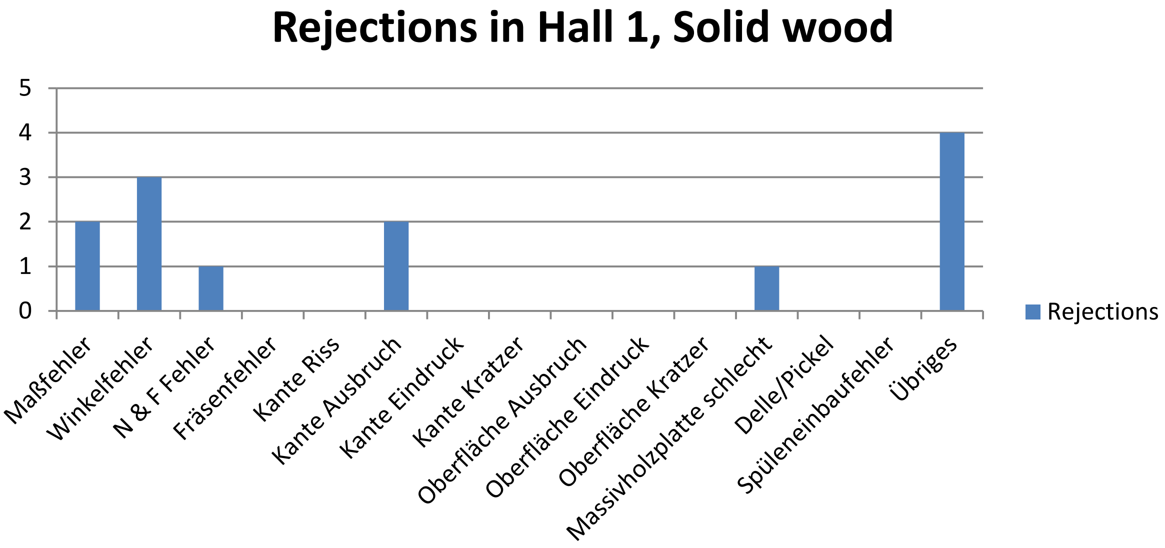

Figure 6-5: Rejections of solid wood worktops in Hall 1 (Möller & Sahleström, 2011).

Figure 6-6 shows the rejections at stations in production hall 1. It should be stressed that at the work stations “Spüleneinbau” and “Endkontrolle Spüle”, no rejections were registered. The final control is less representative in comparison with laminate worktops. This might be due to the longer cycle times at the station “Massivholz HB”, where every solid wood worktop is refined and has the operator’s full attention, since every worktop requires further sanding and in some cases re-work due to the preceding work station.

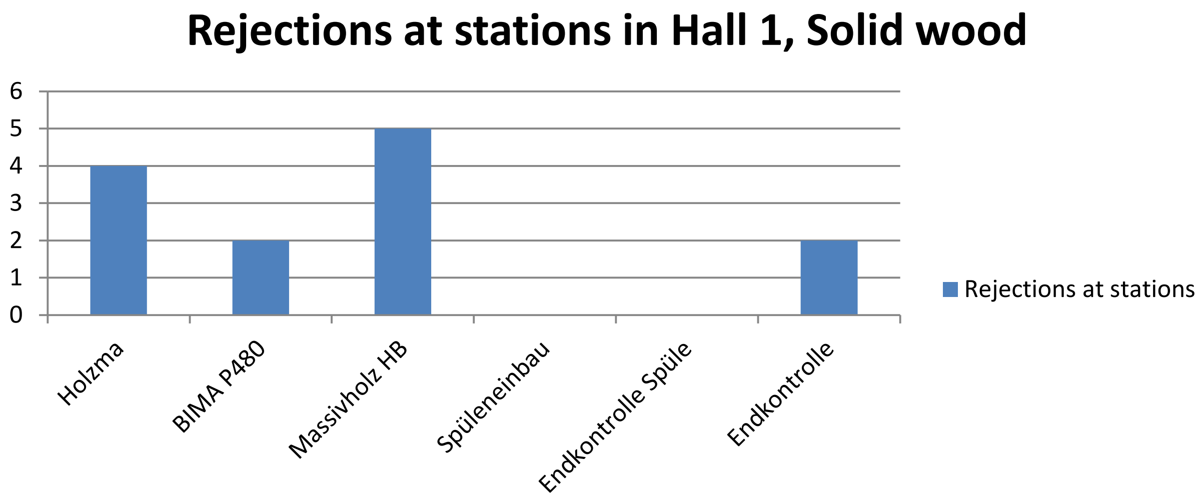

Figure 6-6: Rejections at stations in Hall 1, Solid wood worktops (Möller & Sahleström, 2011).

6.1.1.3 Laminate worktops in Hall 5

In difference from production hall 1, the PPM measurements in production hall 5 could only be conducted at two stations, “Transport area to Hall 1” and “Endkontrolle”. At these two stations, all rejections were detected before being processed. Figure 6-7 illustrates the rejections in production hall 5, where no specific quality parameter was more common than others. The same categorization for laminate worktops in production hall 1 can also be used for production hall 5, where 86 % of the rejections can be categorized into the following groups:

- Dimensional errors, 17 %.
- Visual damages on surface and edges, 46 %.
- Visual errors in laminate, 23 %.

The rejections considered as “Übriges” corresponded to four worktops and were decided not to be further investigated.

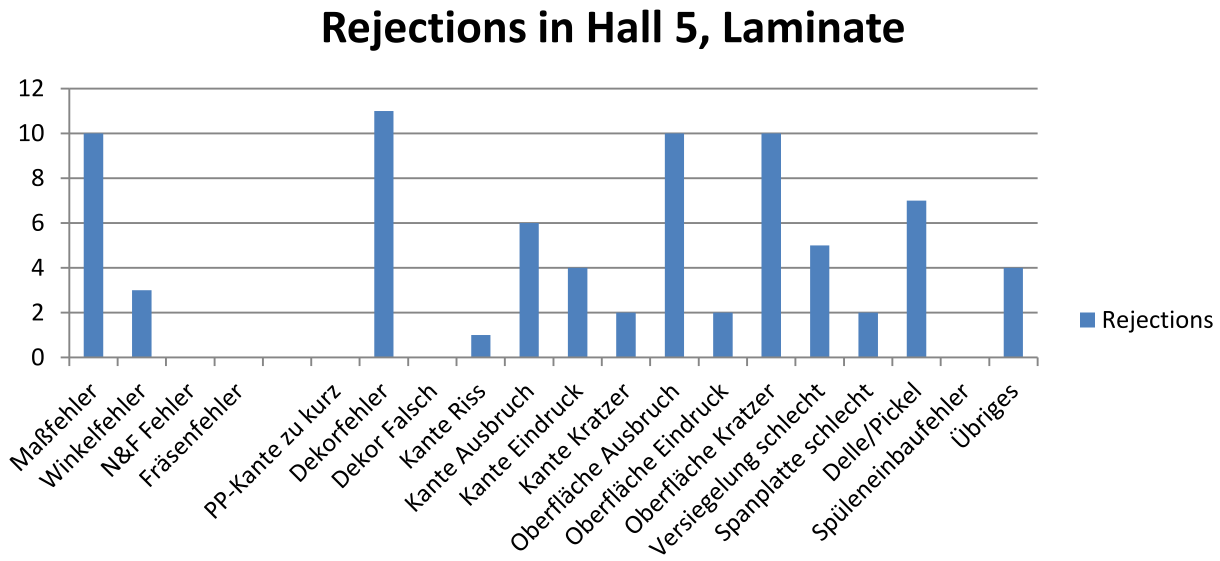

Figure 6-7: Rejections of laminate worktops in Hall 5 (Möller & Sahleström, 2011).

Figure 6-8 illustrates the rejection causes in production hall 5, showing that 78 % of the rejections were caused by machines. During an interview with a final control operator in hall 5, a discussion was held regarding the possibility of connecting a rejection to "Maschine" as a rejection cause. The outcome was that the machine cause could be determined, but knowing which machine that had caused the rejection was more difficult. Due to this insight, the thesis authors state that more rejection causes should have been registered as "Undefinierte Faktoren". For future measurements, it would be feasible to break down the machine causes into individual factors, in order to receive more detailed statistics.

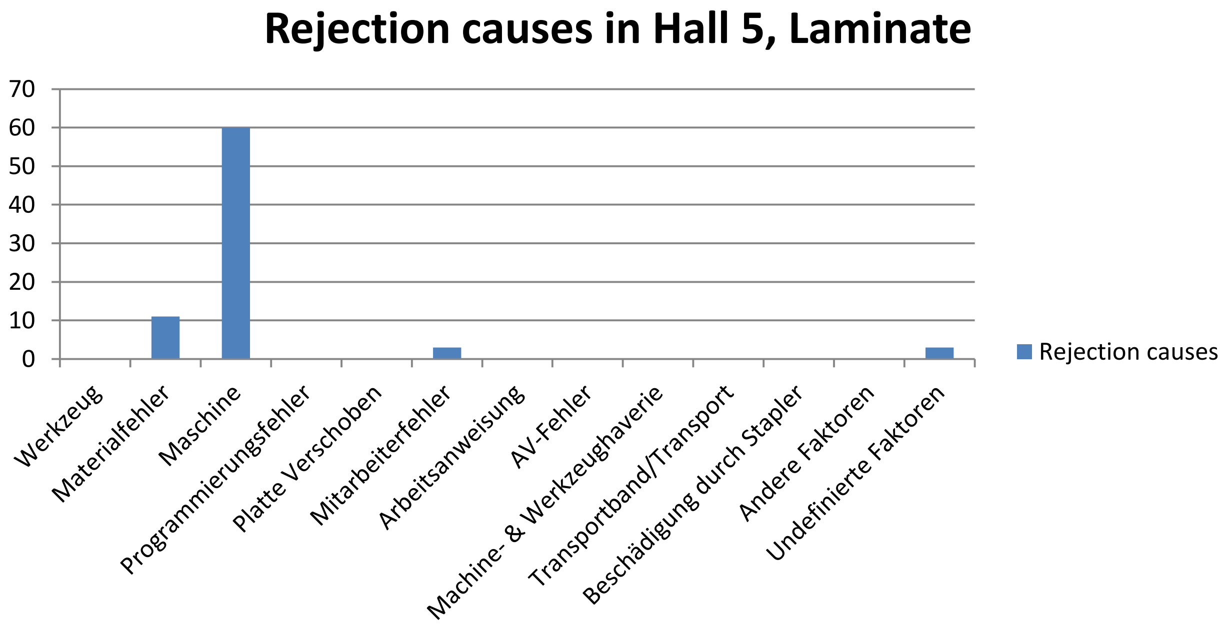

Figure 6-8: Rejection causes of laminate worktops in hall 5 (Möller & Sahleström, 2011).

6.1.1.4 Insights from PPM measurements

Even though not all rejections were registered in the PPM measurements, insights and conclusions can still be made. Interviews with supplier personnel and Figure 6-1, demonstrates an insight that the overall rejection rate is independent of material, production hall and batch size, which could indicate a lack in the holistic work methods. For laminate worktops, the three main groups of quality parameters are similarly distributed in both production halls, representing around 80 % of all rejections. This statement further enhances the mentioned indication.

During the PPM measurement, more rejections should have been registered as “Undefinierte Faktoren”. It is critical to register rejection causes as unknown in order to validate the collected data. Also, it is essential to have more operator involvement in order to obtain more detailed information as well as the possibility to trace rejections upstream in the production flows. Since the rejection rate, according to supplier personnel, normally varies between 2-2,5 %, further improvements lies within increased operator involvement of product quality measurements.

12 % of all registered rejections in production hall 1, and 5 % in production hall 5, have been registered as ”Übriges”. Consequently, to receive better information, more defined quality parameters are necessary.

The number of worktops detected before stations show that the supplier’s work with internal customers is vague. Therefore non-conforming products in production hall 1, which are refined at work stations with shorter average cycle time, has a higher risk of reaching end customers.

90 % of all IKEA products start in hall 5, where 70 % are also packaged. In production hall 5, 78 % of the rejection causes are considered as “Maschine”. Therefore, the risk of non-conforming IKEA products can be decreased by implementing process control.

The operators were not used to report re-work, which due to its low registration rate was reflected in the PPM measurements. The thesis authors suspect that the true amount of re-work was higher than registered. However, since no continuous measurements of re-work are performed at the supplier, this hypothesis can not be confirmed. The thesis authors claim that re-work corresponds to hidden quality issues. For full detection and improvements within product quality, the handling of re-work should be performed similarly to the handling of rejections.

6.1.2 Quality control

6.1.2.1 Product quality control within the manufacturing

Throughout the manufacturing, general management advices for product quality control are used. However, depending on which operator or department that was interviewed, the frequency and control requirements differ. This is due to the fact that written instructions regarding product quality control, apart from the final inspection, are non-existent. This implicates that the official responsibility, ensuring fulfilment of customer requirements regarding product quality, is transferred to the final inspection alone. With this approach, the risk of non-conforming products reaching end customers strongly depends on the operator performance at the final control station.

Detecting rejections as close to the source as possible is an important success factor for continuous improvements. Therefore, the execution of product quality control must be well structured in order to detect rejections further upstream in the production flows. When detecting rejections towards the end of the production system, it requires time-consuming research from the engineering department to determine the rejection causes and sources, which is sometimes impossible due to the lack of time and information.

Interviews with operators indicate that, when detecting a rejection, there is no time for immediate reflection regarding the rejection cause. The rejected worktop is put aside until a shift leader decides the necessary action. The responsibility of the operator does not concern product quality, but rather production rate and production volume. An observation by the thesis authors is that the supplier's time fixed PPC system could have a negative effect on product quality, especially when production volume is fluctuating. The combination of larger production volumes, no possibility to produce in advance and no written instructions regarding product quality control implies an increased risk of poor quality. There is a risk that quality performance and control will be less prioritized than the general management advices state, especially during extended working days with high work pressure when operators are evaluated by production volume.

Where and how often to quality control within the manufacturing is fundamental for internal improvements and preventions of claims. However, to determine what to control is crucial in order to meet customer expectations and requirements. The thesis authors observed a weak transfer of IKEA product requirements, from received documents to stated product CTQ parameters controlled in the production. This transfer can be seen as going through two parts of the quality department; one receiving and handling the IKEA documentation, and one responsible for translating requirements into product CTQ parameters as well as their implementation. Due to absence of supplier experience within mentioned areas, an inquiry arose if IKEA could coach and advice the supplier of how to work with these questions and how to execute best practise.

6.1.2.2 Process control within the manufacturing

Except for the final control station, the supplier's manufacturing processes are not documented. This is a stated requirement in ISO-9000, a certification that the supplier intends to obtain in the future.

The supplier has just taken the initiative of a smaller project concerning process CTQ parameters within glass worktop manufacturing processes. Apart from that, process CTQ parameters are not documented, implying the risk of operators considering different factors as critical. The thesis authors investigated this issue by executing a process mapping, identifying process CTQ parameters together with operators for the procedure of building-in sinks, a process from which the majority of claims were produced in 2010. The process is explained in detail in Appendix 4. The process and CTQ parameters were discussed with quality department personnel.

The supplier took the following actions in 2010, resulting in an improved process:

1. Cleaning of laminate and sink contact surfaces with cleaner and adhesion agent.
2. Drying of glue set to at least 15 minutes before using casting resin.
3. Use of optimal mixture of casting resin components.
4. Optimal cleaning and removal of glue at the very end of the process.

The operators and department personnel generally had the same opinion regarding the process execution and the CTQ parameters. However, two major process deviations were noticed. Firstly, the operators used the wrong color of glue, which is not critical for the function but important for artistic reasons. The operator claimed that the basis of glue color depends on laminate color, whereas it actually depends on sink material. Secondly, both laminate and sink contact surfaces should be cleaned with cleaner and adhesion agent; though cleaning of the laminate was forgotten. According to quality department personnel, both contact surfaces must be cleaned. This could be a cause of claims due to the fact that a part of the contact surface between the laminate and the sink detaches over time. This is a good example of a well-functioning but not documented process, where certain process steps (glue) and CTQ parameters (adhesion agent) are changed by operators over time due to the lack of follow-ups. It shows the importance of clear process instructions, communication of CTQ parameters and their importance as well as the performance of process audits.

This very best example of process control at the supplier shows the supplier's general quality approach, which lacks the implementation of structured processes feasible for continuous improvements. The current mapping and improving of processes without documentation or further follow-ups are insufficient. During interviews with management emerged an ISO-9000 certification as one of the future quality objectives. Having a process perspective is a requirement and key factor of a successful quality work. In order to reach this objective, the supplier must be more process oriented; both regarding process supervising and process ownership. Related to the example above, since the process and CTQs of building-in sinks are well known, the supplier should be able to choose a process supervisor responsible for the correct process execution and a process owner ensuring the continuous improvement of the process.

The documentation of process control of the CNC machines is insufficient. The daily process control at CNC machines is a non-stated procedure which is not registered and therefore impossible to follow-up. The monthly test is documented, but is according to interviews not used by any departments at the supplier. The lack of process control and its documentation eliminates the possibility to draw conclusions between rejections and machine performance; an important part of continuous improvements.

6.1.3 Measurement system

The supplier's measurement systems are deficient, both regarding system construction and data collection. This hinders the usage of continuous improvements, since the engineering department receives insufficient information. The major shortcomings are:

- Operators do not perform the measurements. The operators have more information about rejections than is transferred to the measurement system, resulting in valuable information not being used. This was obvious when analyzing the results of the PPM measurements, which could not be applied as planned.
- Rejections are collected and registered at certain collection points in the manufacturing. It is not clearly stated which work stations that are connected to which collection point. Consequently, it is not possible to link a rejection to a specific work stations.
- Especially in hall 1, the possible quality parameters to choose in the measurement system are too few and too general, implying that the correct information is not possible to register.
- Quality parameters are mixed with rejection causes in the measurement system of production hall 5. It is essential to separate these terms since each rejection has a cause, which should be prevented by continuous improvements.
- There is no possibility to connect a quality parameter with a cause in the measurement system, meaning that the measurement system does not support cause and effect relations. During interviews with production operators, it was obvious that the causes were known in many cases,

implying that valuable information is not registered. In order to secure data credibility when the cause is unknown, it is crucial to have an unknown factor to choose from.

6.1.4 Continuous improvements and follow-ups

Due to the insufficiency of collected data in the measurement system, engineering department personnel spends valuable time on the shop floor adding and collecting needed information to initiate improvement projects. Engineering department personnel possess good knowledge regarding project planning and execution of continuous improvements. E.g. interviews showed that, during 2010-2011, the total rejection rate for all materials at the supplier decreased from 7 % to 4 %, due to smaller improvement projects. Hence, the thesis authors claim that the knowledge and work methods of the engineering department will not be a hinder when working with continuous improvements in order to improve product quality.

The supplier has no structured approach of utilizing the operators' deeper knowledge regarding daily production issues. According to interviews, the suggestion board system is no longer successful, mainly because of absence of support systems and loss of operator interest due to lack of information, suggestion follow-ups and rewards. Also, the main communication channel between operators and the engineering department goes through the shift leaders, indicating that direct channels for operators to highlight problems are limited. Likewise, information sharing to operators from departments is insufficient and unstructured. During interviews, quotes like "the operators do not need to know the status of the production" were given. The thesis authors indicate this to be an obstacle if the supplier would like to increase operator involvement and motivation.

The thesis authors have identified gaps in the communication; both between departments as well as between departments and the shop floor. There are numerous examples of isolated activities that could have greater output if coordination would be increased, four of which are mentioned below:

- Work regarding IKEA documentation should be better integrated within the quality department activities as well as within the purchasing department. The quality department should translate the IKEA requirements into tolerances and CTQ parameters. Together with the purchasing department, IKEA requirements should be communicated to sub-suppliers as a foundation of sub-supplier requirements. However, since IKEA requirements are new and not fully developed, this work is difficult since tolerances in technical descriptions are vague.
- There is a difficulty in having many external communication channels, where changes and decisions regarding product documentation are made. Therefore, the external communication with IKEA regarding product documentation should be structured and standardized together with IKEA.
- The quality department is responsible for setting the structure regarding quality work through documentation and control. The engineering department, based on this structure, executes improvement projects in the manufacturing. E.g. the quality department sets the frame for product quality control, whereas the engineering department uses the collected data to define areas in need of improvements. However, a structured coordination between the mentioned departments is missing. According to interviews, neither common goals have been set nor are continuous meetings held.
- Interviews indicate, that information regarding rejection rate and claim rate is not regularly shared between the quality and engineering department. This implies that no department receives a

complete picture showing the correlation between rejections and claims. Since the engineering department is responsible for carrying out regular improvement projects in the manufacturing, this also implies that in these projects, claim statistics are usually not taken into account.

Since there are no work descriptions with stated responsibility at the shop floor, operator responsibility to continuously improve the production has not been implemented. As stated in in chapter 6.1.2, shift leaders must focus on maintaining the production rate; quality and improvements are not prioritized. Logically, this prioritization is spread to the operators. The lack of responsibility regarding continuous improvements in the production halls creates a huge gap between the manufacturing and the engineering department. Consequently, the smaller projects executed by the engineering department will probably not be enough to improve the level of quality in the future. The thesis authors address this to be a management issue. The shift leaders and operators will perform and prioritize areas of which they will be evaluated. If work regarding quality is to be prioritized at the shop floor, management must take actions e.g. adding resources or changing the shop floor culture and responsibility towards quality.

The supplier does not have a quality system, which is a major obstacle when working with continuous improvements. It is difficult to stepwise improve a business without clear areas of responsibility, structure and documentation. Without a quality system, there is a risk that single improvement projects will not result in sustainable solutions that permanently eliminates errors. Also, not having structured documentation implies a risk for the supplier and their customers. Vast knowledge will be lost in the case of an operator leaving the company, due to the supplier’s flexible production with numbers of craftsmanship stations in non-predefined production flows. Interviews indicate that one of the major quality issues at the supplier has been the absence of management involvement and commitment. Quality management, goals, objectives and policies are non-existent. However, a quality manager was hired in December 2011 and improvements of the supplier’s quality work are to be expected. Though, it must be stressed that previous IKEA quality assessments have also highlighted the management commitment issue.

The order process, from order receiving to production papers, was by the thesis authors considered as not critical to product quality. Although the order process is complex, no indications from the PPM measurements or interviews indicated issues affecting product quality.

6.1.5 The CBD model

The data used in the CBD model were collected from different sources throughout the master thesis, shown in Table 6-1. Data which the supplier could not or would not provide were collected using other sources.

Cost parameters	Source	Process parameters	Source	Performance parameters	Source
Tool cost, k_A	Authors' estimation	Cycle time, t_0	Supplier	Material wastage, q_B	Supplier
Material cost, k_B	Authors' estimation according to values from other supplier	Setup time, T_{SU}	Supplier	Rejection rate, q_Q	PPM
Machine cost, k_{CP}, k_{CS}	IKEA estimation	Time window production time, $T_{P,tw}$	PPM	Downtime ratio, q_S	Calculated
Wage cost, k_D	IKEA estimation	Degree of utilization, U_{RB}	Supplier	Rate of re-work, q_{RW}	PPM
Claim penalty cost, k_{CL}	IKEA	Time window batch size, $N_{0,tw}$	Supplier	Rate of re-use, q_{RU}	PPM
		Orders, $N_{orders,tw}$	Calculated	q_{CL}	IKEA/Supplier
		Single batch size, N_0	Set to 1	$q_{CL\%}$	IKEA/Supplier

Table 6-1: Input data for parameters at Lechner (Möller & Sahleström, 2011).

Tool costs were used for manual work stations, where new tools were expected to be purchased every half year. Material costs were estimated by the thesis authors according to values from the other supplier, and were considered a proper estimation of the supplier's material costs. The material costs include purchase price and transportation costs from the sub-suppliers to the supplier. Investment, renovation, facility and variable costs for machines were estimated together with IKEA personnel. Since regular maintenance is usually performed by the operators, hourly maintenance costs were set to the hourly wage cost. Wage costs for operators were estimated by IKEA personnel.

6.1.5.1 CBD model as a single unit approach

Figure 6-9 contains the supplier's cost structure of the four laminate worktops, chosen in chapter 5.1.3. The affecting cost and performance parameters regarding claims are not part of the cost structure of specific worktops and are therefore not shown. Figure 6-9 indicates that manufacturing cost of customized laminate worktops is highly affected by the material cost, which makes up more than 50 % of the total cost in almost all cases. The material cost of case 3 also includes the material cost of the sink. Machine production costs increases with longer cycle times of machine processes and vary between 11-18 % of total costs. Machine downtime cost varies between 3-5 % of the total cost. The wage cost increases with longer cycle times, both regarding machine processes and especially regarding manual work stations. Wage cost varies between 13-33 % of the total cost. Tool costs are negligible.

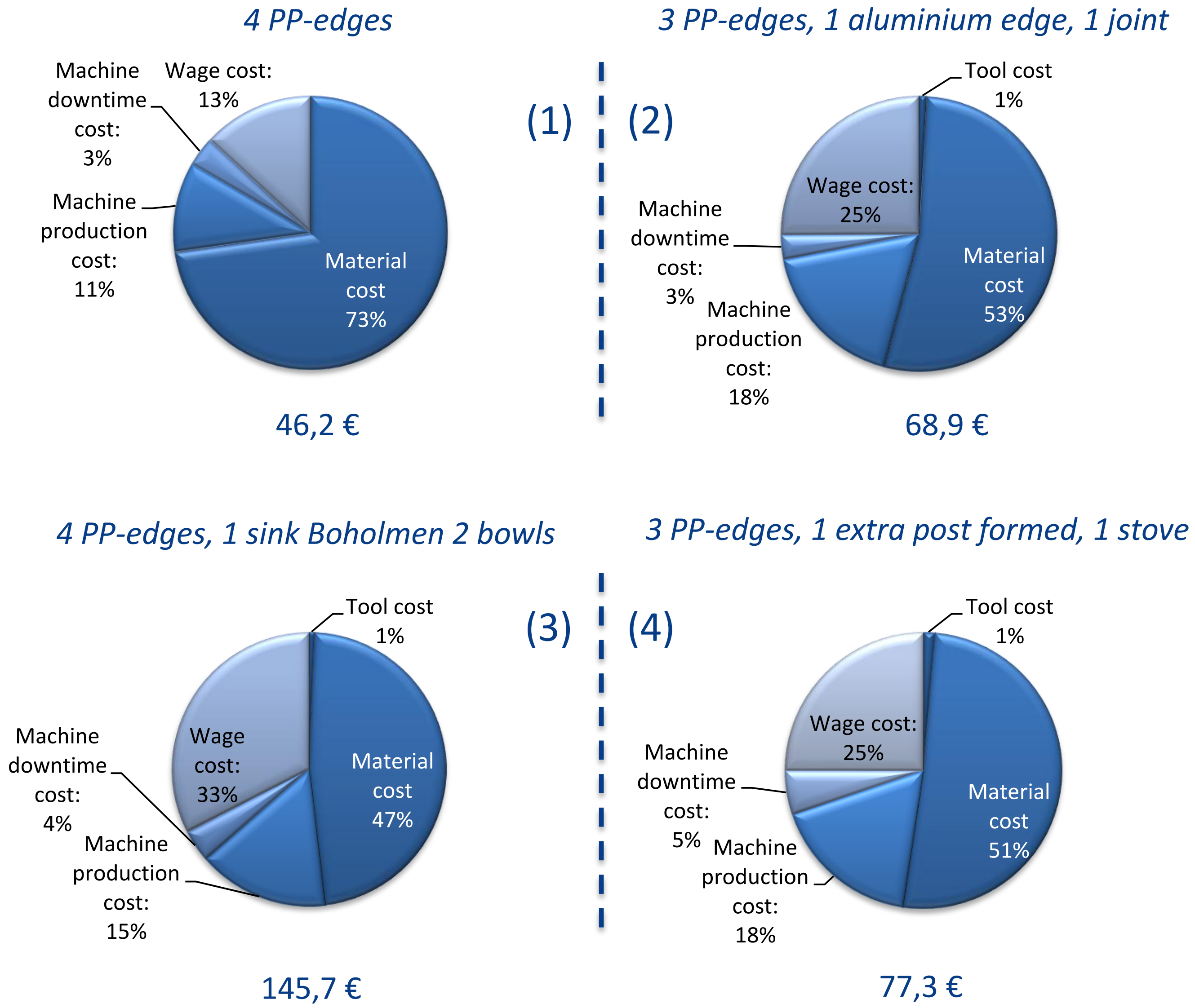

Figure 6-9: CBD of four laminate worktops (Möller & Sahleström, 2011).

Figure 6-10 presents the cost structure of the three solid wood worktops chosen in chapter 5.1.3. The material cost varies between 44-58 % of the total cost, whereas the material cost of case 3 also includes the material cost of the sink. Machine production cost constitutes between 9-16 % of the total cost, whereas machine downtime cost varies between 5-6 %. The wage cost constitutes between 27-34 % of the total cost, which in comparison with laminate worktops corresponds to a higher average wage cost, due to the fact that all solid wood worktops requires manual refinement. Tool costs are negligible.

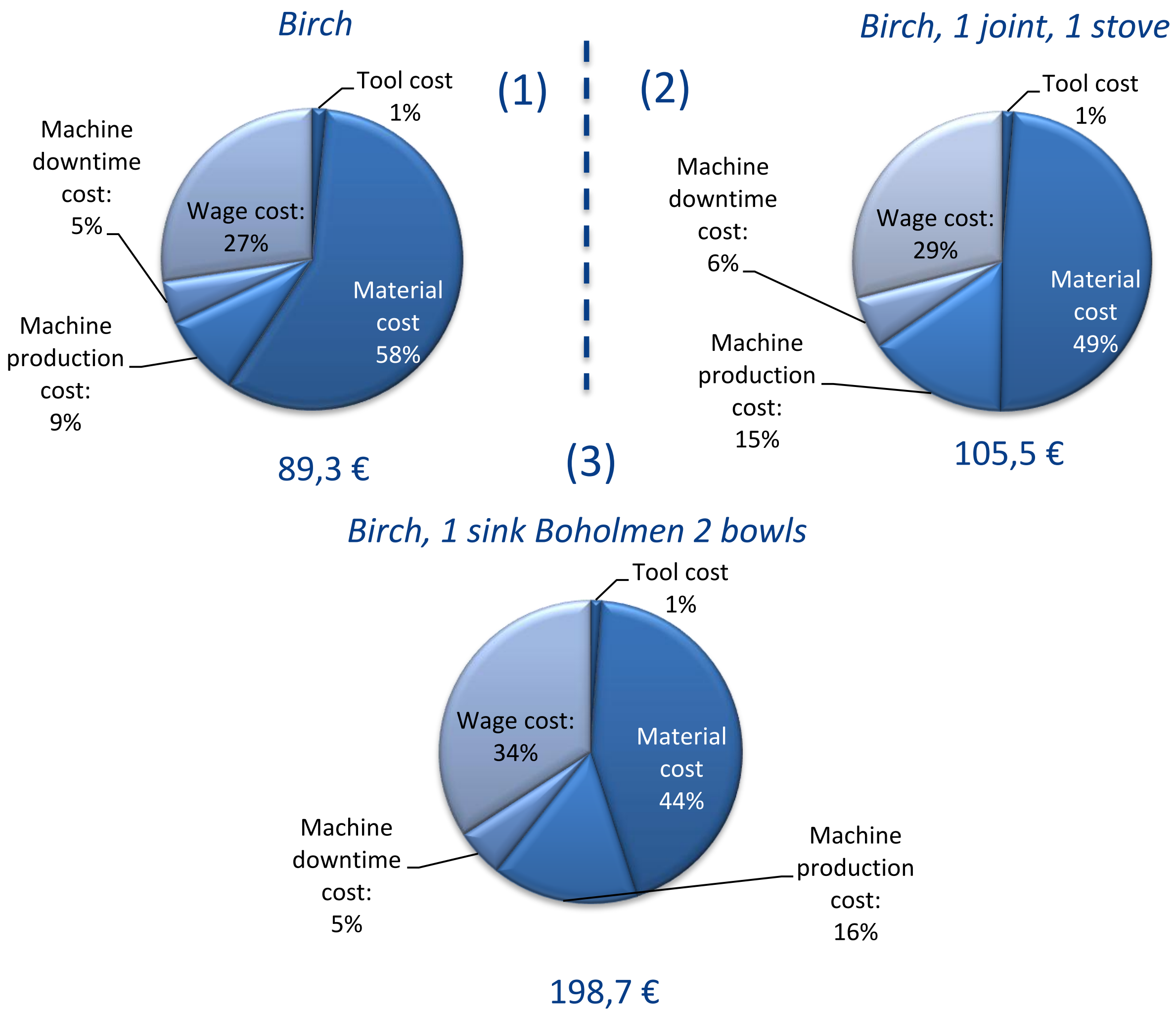

Figure 6-10: CBD of three solid wood worktops (Möller & Sahleström, 2011) .

6.1.5.2 CBD model as a system approach

Due to the production flows at the supplier and that the supplier is not only producing for IKEA, the following estimations were made in order to calculate the cost of the average PERSONLIG worktop:

- The cost structure of the average PERSONLIG worktop is based on 30 % of the manufacturing costs from production hall 1 and 70 % of manufacturing costs from production hall 5, based upon production flows stated in chapter 4.3.3.1.
- Since IKEA and the supplier do not agree upon the actual claim rate, both the claim rate according to IKEA and the supplier are used, as stated in chapter 4.1.2.2.
- The rejection rate in the PPM measurement was by the supplier considered as too low. Since the system approach is used to determine the economic effect of preventive root-causes, a rejection rate of 2 % is used.
- Only laminate worktops are taken into account.

Figure 6-11 demonstrates two cost structure scenarios of the average PERSONLIG worktop. The figure indicates that the material cost constitutes the major cost, and the wage cost has the second largest cost effect, making up almost a fifth of the total cost. The total machine costs add up to between 15-16 %, whereas the tool costs are negligible. The claim penalty cost varies between 3-8 % of the total cost depending on the percentage of claimed orders.

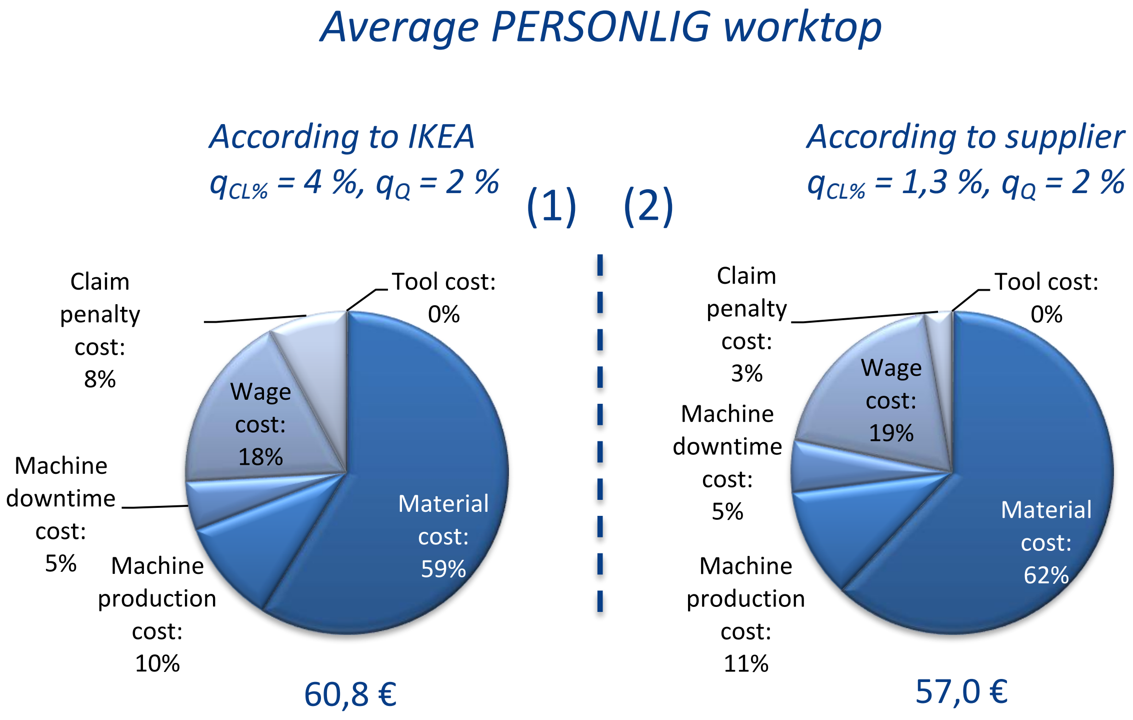

Figure 6-11: CBD of the average PERSONLIG worktop (Möller & Sahleström, 2011).

The annual economic effect of root-cause preventions are calculated by multiplying the yearly amount of worktops produced with the manufacturing cost of the average PERSONLIG worktop at the supplier, then adjusting the performance parameters regarding quality, which is claim rate and rejection rate. Decreasing claims and rejections, due the execution of root-cause preventive actions, results in a lower average PERSONLIG worktop cost, implying a cost savings potential. The supplier produces in average 276 700 PERSONLIG worktops yearly. The cost savings are presented in chapter 7.1.3.

6.2 Danform

6.2.1 PPM Measurement analysis

The PPM measurements at the supplier were conducted during week 43-45, 2011. The results are presented and discussed below. Unfortunately, operators did not register all rejections in the PPM measurements. The reasons for this might have been that rejections also occurred during the night shift, operators were not informed by one another about the PPM measurements during the shift changes and rejections considered as sub-supplier related were not all filled in.

The PPM measurements showed a rejection rate of 2,53 %, whereas the supplier’s measurement system displayed the rejection rate to be 4,26 % during the same period. This is illustrated in Figure 6-12, shown together with the batch size. The supplier might argue the rejection rate of 4,26 % to be too high, since the supplier calculates the rejection rate without rejections related to sub-supplier. According to the supplier, the average rejection rate during 2011 was 1,93 %. This number increased between August and October when the average rejection rate was 2,44 %.

The re-work registered in the PPM measurements showed a rate of re-work of 0,49 %, whereas 50 % of re-work causes points to “AV-Fehler”, 13 % to “Maschine & Werkzeug” and 13 % to “Undefinierte Faktoren”.

One of the shifts detected 57 rejections before processing and 42 rejections were caused during processing. The other shift detected 71 rejections before processing and 63 rejections were caused during processing. However, shift and work station comparisons were not feasible since operators switched between shifts and work stations.

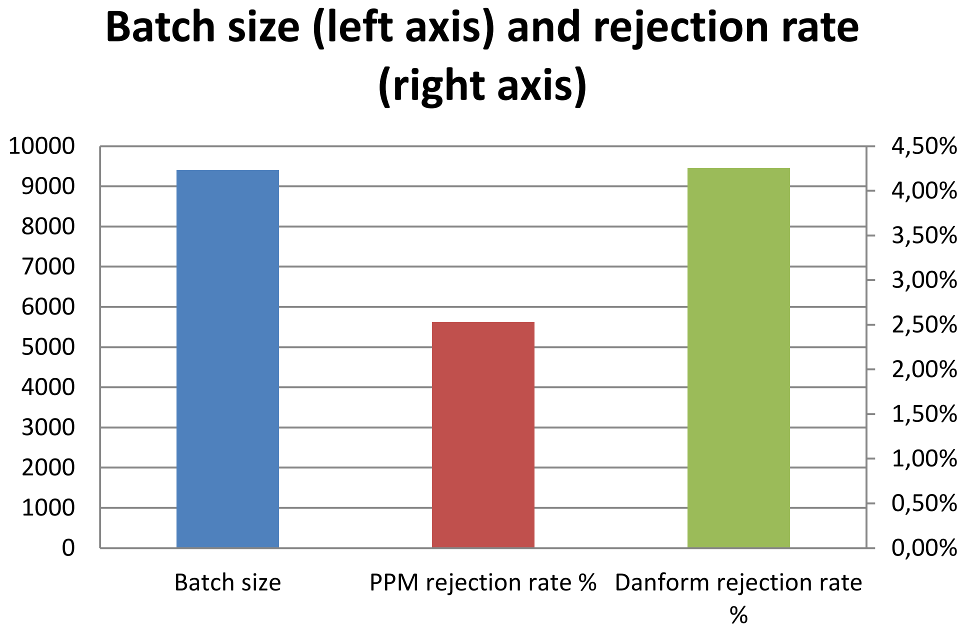

Figure 6-12: Batch size and rejection rate at Danform (Möller & Sahleström, 2011).

6.2.1.1 Laminate worktops

Figure 6-13 shows the rejections for each quality parameter. As seen in the figure, the quality parameter "Übriges" is overrepresented. However, the thesis authors managed to further deduct the following quality parameters from "Übriges" through interviews; 23 rejected worktops were considered completely broken due to process failure during milling operations, 3 rejections were considered as measurement errors caused by the order department and 8 were considered as gluing errors in laminate.

No specific quality parameter can be considered more frequent than others. However, 65 % of the rejections can be categorized into three major groups:

- Dimensional errors, 5 %.
- Visual damages on surfaces and edges, 45 %.
- Visual errors in laminate, 15 %.

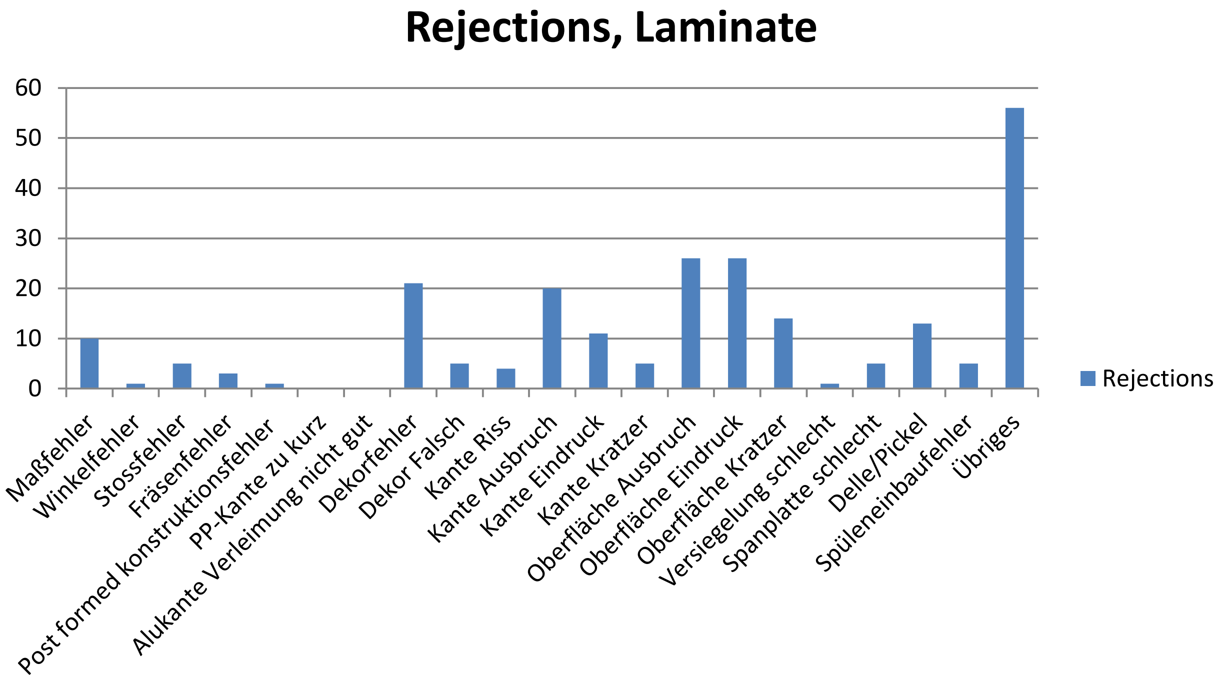

Figure 6-13: Rejections of laminate worktops (Möller & Sahleström, 2011).

Figure 6-14 demonstrates the rejection causes, from which the most common ones were:

- "Materialfehler", 34 %.
- "Undefinierte Faktoren", 21 %.
- "Transportband/Transport", 12 %.
- "Platte Verschoben", 10 %.

78 % of the rejections caused by "Undefinierte Faktoren" were detected before processing. The high amount of unknown factors indicates that there are many unknown affecting factors within the manufacturing system, showing a need of operators' professional development through internal educations and internal follow-up meetings.

The results from the two latter rejection causes were further discussed with operators. “Transport” errors were caused by two buffer cranes and “Platte Verschoben” errors were due to lack of vacuum pressure at CNC machines.

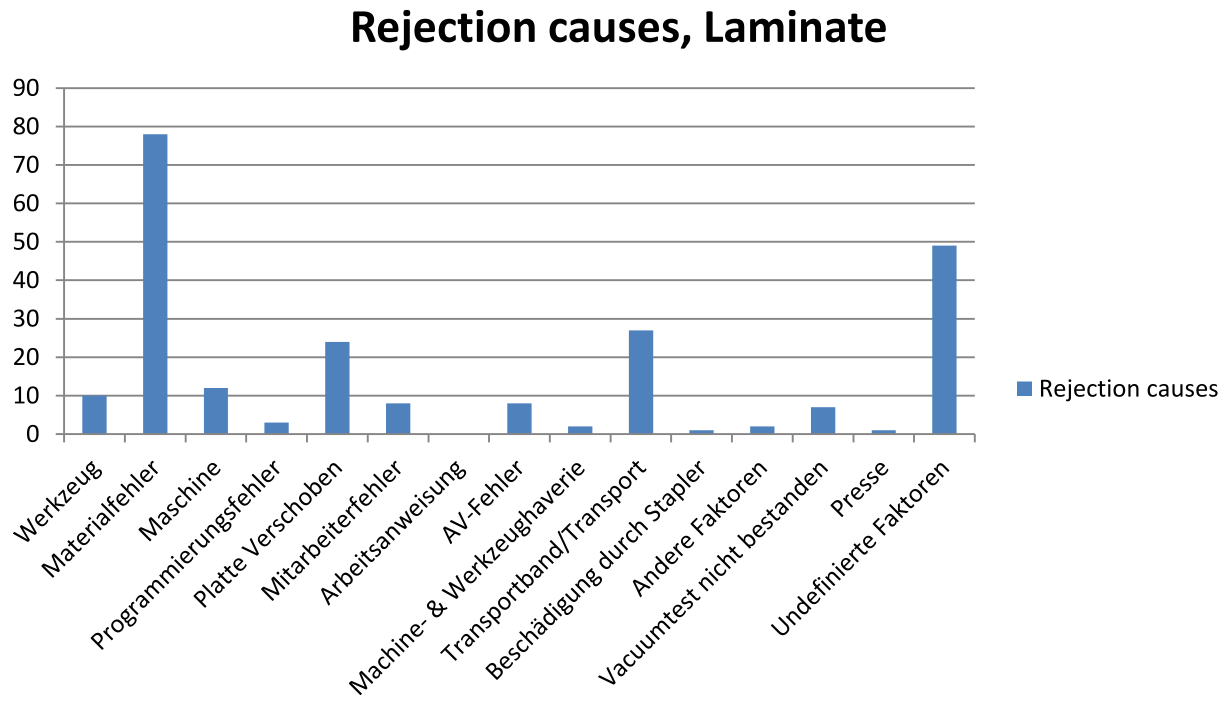

Figure 6-14: Rejection causes of laminate worktops (Möller & Sahleström, 2011).

Figure 6-15 illustrates rejections and the rejection rate at each work station. The PPM measurements showed that 55 % of all rejections were detected before being processed, and these rejections were mostly considered to be caused by material, unknown and transport factors.

The highest amount of rejections was at the two “Novimat” stations, however due to the large amount of processed worktops at this work station, it corresponded in the third lowest rejection rate. The majority of the rejections at these stations were due to material factors and unknown factors. “Endkontrolle” had a low amount of rejections, but when including 24 worktops in need of re-work, the rate of non-conforming products at this station increased to 0,49 %. This is a low rate, indicating that the majority of non-conforming products are detected upstream in the production flows.

“Alukante” had a high registered rejection rate, out of which 81 % were detected before processing. Interviews with operators concluded that this was due to longer cycle times and better lighting. This was also the case for rejections at “Spüleneinbau” and “Post formed”.

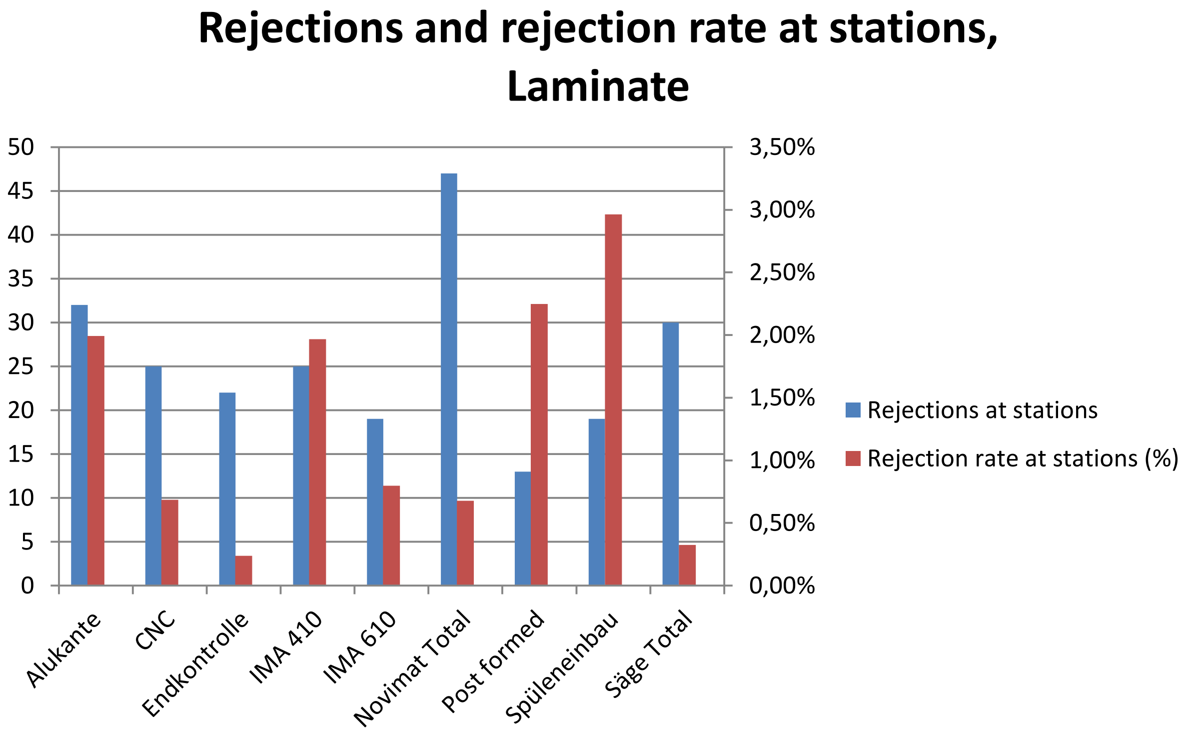

Figure 6-15: Rejections and rejection rate at stations, Laminate (Möller & Sahleström, 2011).

6.2.1.2 Insights from PPM measurements

Supplier personnel performed the PPM measurements according to instructions given by the thesis authors. Interviews with operators revealed their knowledge regarding specific quality problems, causes and solutions.

The high amount of non-conforming products caused by unknown factors shows a correct operator performance of the PPM measurements. However, it also reveals the complexity of solving quality problems since causes are unknown. Consequently, cooperation and sharing of knowledge are essential in order to identify and eliminate these causes.

Factors such as longer cycle time and better lighting showed a significant effect in order to detect non-conforming products, demonstrating the importance of quality control conditions.

The operators were not used to report re-work, which was reflected in the PPM measurements due to its low detection rate. The thesis authors suspect that the actual amount of re-work was higher than registered, however since no continuous measurements of re-work are performed, this hypothesis can not be confirmed. Re-work corresponds to hidden quality issues. For full detection and improvements within product quality, the handling of re-work should be performed similarly to the handling of rejections.

6.2.2 Quality control

6.2.2.1 Product quality control within the manufacturing

The use of a final control means that each product is scrutinized before packaging. The supplier has chosen not to use this control method. The method chosen denotes a transfer of the control responsibility, from the final control upstream in the production flows. Furthermore, the supplier attaches great importance to process control for diminished necessity of product control at each work station. The thesis authors find this approach of quality control to be an important step in transferring and distributing quality responsibility to the shop floor. However, in order to succeed with this approach, the quality control system must be constructed from a holistic perspective.

Interviews with operators indicate that quality control is not fully performed according to work descriptions. Depending on which operator that was interviewed, product quality control is performed both to a greater and lesser extent than stated. A customized production requires clear instructions regarding what to control, where to control it as well as to what extent. Also, performance of continuous follow-ups is essential, ensuring both correct prosecution and improvements of work descriptions. This would render the opportunity to highlight improper control conditions, described in chapter 6.2.1.2.

Currently, 2-3 worktops per work station and shift are thoroughly controlled, whereas the final inspection performs visual damage control on 25-50 % of the worktops. Interviews and observations by the thesis authors demonstrate that work descriptions have not been written from a holistic perspective, and with the current approach, there is a statistic risk that some produced worktops are not controlled by any operator. In order to eliminate this risk, more precise statements are needed regarding which factors at each work station that are critical to control, since each worktop has its own production flow. Also, spreading the holistic view to operators is essential. Firstly, in order to eliminate random control, the operator must know his responsibility from a system perspective for a full understanding of his role in the quality chain. Secondly, operator responses regarding the actual purpose of the final control station differed between “final controlling” and “packaging”. Thus indicating that the supplier has not communicated this purpose thoroughly enough, resulting in an operator reliance on the inexistent final control.

The thesis authors would like to distinguish the difference between detecting non-conforming products at an early stage, implying cost savings, and ensuring top quality to the end customer. According to chapter 6.2.1.1, 60 % of the rejections were considered as visual defects derived throughout the manufacturing, indicating the sensitivity of this type of product. In combination with the fact that the IKEA SQS requires a final control, the thesis authors emphasize that the supplier should implement a 100 % final control on visual defects. Extended final control should be discussed between IKEA and the supplier.

6.2.2.2 Process control within the manufacturing

As stated in chapter 6.2.2.1, the supplier attaches great importance to process control. When a process becomes stable and reliable, the supplier’s extent of product quality control within the process will decrease. Since the process control is based upon tolerances, the importance of having the correct tolerances is vital for product quality. Process control measurements are collected by the quality department once a week. In addition to the fact that the supplier has mapped and documented the manufacturing processes, the thesis authors claim that the supplier has a good understanding of the process performances. However, two areas should be mentioned, even though the supplier performance within these areas is not considered an issue:

- It is important to be aware of the differences between mass and customized production from a process control point of view. The above described approach is suitable within mass production and similar stages within customized production. However, there is a risk in viewing the more flexible processes as static. These processes require a larger extent of product quality control.

- Manufacturing tolerances have been determined by the supplier without IKEA requirements. Since tolerances define acceptance, they should be based upon customer requirements. There is a risk that a change of tolerances could be problematic, due to the vague documentation. For further development, a greater interaction between IKEA and the supplier would be desirable.

Currently, the supplier experiences quality issues regarding the procedure of building-in sinks. The process is structured, documented in detail and measured. Neither the supplier nor IKEA knows the solution to these issues. These issues are being investigated by both parties; therefore the thesis authors chose to exclude this from the master thesis.

6.2.3 Measurement system

The supplier's measurement system has a good basic construction; however there are various areas in need of improvements where both information structure and information quality are weak; key issues for performing continuous improvements. An improvement of the measurement system would be to introduce the possibility of connecting cause and effect in all possible cases, four of which are presented below.

- It is not possible to connect the order department, as a cause, to a quality parameter. This means that the order department can not receive specific continuous feedback from the measurement system, regarding which rejections that can be referred to the performance of the order department.
- It is not possible to connect a quality parameter to an internal transport cause. As a result, the information in the measurement system does not indicate which worktop damage that occurred during internal transportation.
- Quality parameters referring to damage errors are not possible to connect to rejection causes, even though the rejection causes might be known. Without correct instructions of how to report rejections, these errors can easily be put under different categories, which would decrease data validity.
- It is not possible to connect a programming error to a quality parameter. This is of importance since programming errors are connected to different quality parameters, as shown in the PPM measurements, where programming errors varied between "Stossfehler" and "Übriges".

Since there are no instructions of how to report rejections in the measurement system, two drawbacks have been distinguished. Firstly, the operators do not always report all possible input to the production leader, mainly since the operators are not encouraged to do accordingly. The PPM measurements had a higher amount of registered rejections at certain work stations in comparison with the supplier's measurement system. This should not occur, thus indicating a gap in the reporting to the production leader. Interview responses such as "the operators do not need to know how to report data to the measurement system" and "sometimes there is lack of input to the measurement system, it happens" also support this drawback. Secondly, work stations where rejections are detected are mixed when typed into the system. E.g. each CNC-station is known by at least two different names, where some are used for describing more than one CNC-station. Depending on which operator that reports the rejection, a different station name will be used. This results in unreliable data of where rejections are detected.

6.2.4 Continuous improvements and follow-ups

The quality improvements at the supplier are based upon product quality control and process control in the manufacturing. The product quality control is reported into the measurement system on a regular basis, and process control values are collected once a week. From a system perspective, the following weaknesses have been observed, illustrated with red crosses in Figure 6-16.

- The thesis authors have noticed that the measurement data used by the quality department does not include material defects caused by sub-suppliers. Instead, this data is given to the purchasing department which handles the contact with sub-suppliers; though no evaluation regarding the improvement of sub-supplier quality is performed.
- The order department does not receive any continuous data from the measurement system, which in anyway can not be segmented according to chapter 6.2.3. Both of these issues exclude the possibility of improving existing work methods within the order department.
- Based upon the first two weaknesses, the quality work at the supplier is not performed outside the manufacturing. This implies that a comprehensive view of quality work is missing, as well as coordination between functions affecting product quality.

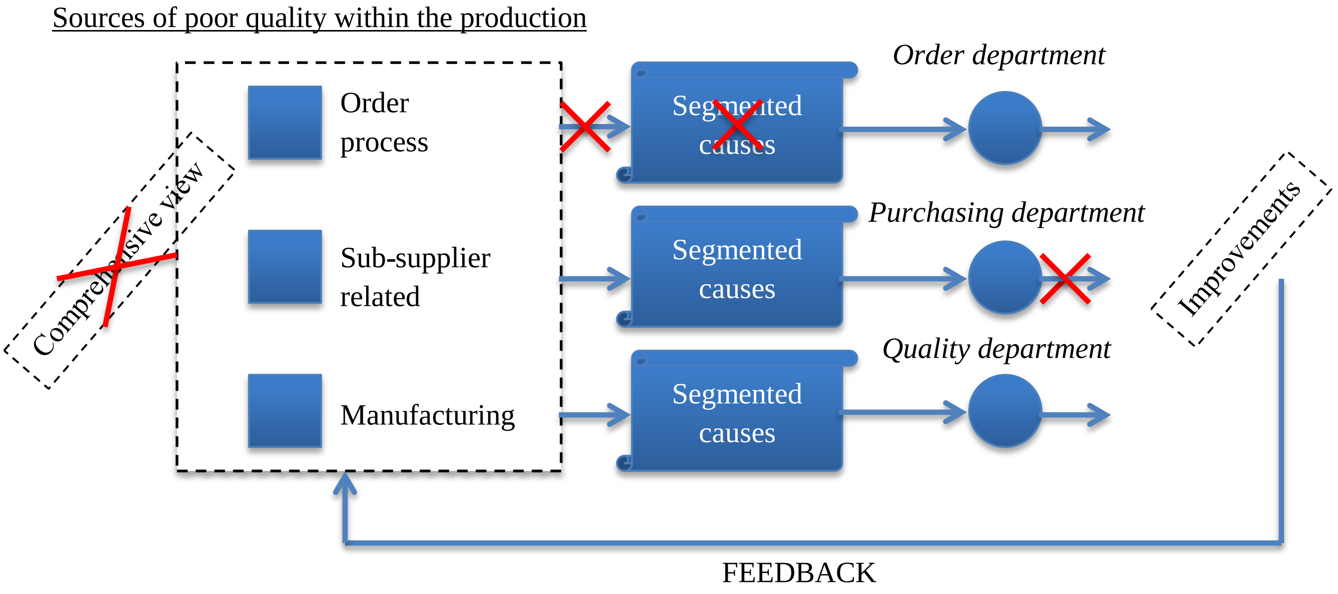

Figure 6-16: System perspective of quality work (Möller & Sahleström, 2011).

Interviews and observations indicate that a major part of the supplier's quality work concerns quality control instead of improvements. The supplier documentation, such as work descriptions, is by the thesis authors considered sufficient. Control and follow-ups of control, such as TYV-reports, demonstrate good internal process knowledge. Also, a foundation for a QMS is established, i.e. the management handbook described in chapter 4.4.6. However, the thesis authors have highlighted four areas of improvements:

- The management handbook is currently not used as a quality structure tool for sustainable improvements on a regular basis. Although the supplier has officially stated company goals in the management handbook, the documented goals related to product quality (goal number 1, 4, 6, 7, 12) have not been quantified nor translated into KPI parameters in order to monitor improvements of the business and departments.
- Since no quality goals have been quantified, these can not be translated into sub-goals in order to identify adequate smaller improvement projects within or between departments.

- The supplier does not have a standardized project structure when working with improvements within the manufacturing. Consequently, the supplier is lacking a project approach towards continuous improvements.
- Currently, there is no dedicated responsible person with the task of executing improvement projects.

The supplier is aware of the fourth area and claims this to be the next step in the future. The thesis authors emphasize that all four areas must be considered and improved, as well as a shift of focus from controlling to improving, in order to take the quality work to the next level, both within departments and from a holistic perspective.

Interviews with operators, when analyzing the PPM measurements, showed a deep operator knowledge regarding smaller problems occurring regularly in the manufacturing, explained in chapter 6.2.1.1. However, plenty of the solutions in the manufacturing were considered to be temporary. The problems could be eliminated more efficiently by using a structured project approach where the gathered knowledge of the operators was to be used. Further interviews with operators showed an inexistence of both improvement meetings and quality performance spread to the shop floor, which the operators found a pity. The currently used suggestion system should be supplemented by adding these measures, for a better use of the operators gathered knowledge.

During interviews, the thesis authors noticed an acceptance towards chronic problems. Firstly, answers such as ”it is not possible to find all rejections”, “such issues occur within manufacturing” and “we are humans, mistakes will be made”, reflect an attitude that errors will always occur with “man” as a common cause. This implies that the supplier is not investigating the chronic problems further, which rules out the opportunity to find and eliminate the true root-causes and improving the underlying processes. Secondly, chronic problems with machines and buffers, leading to downtime, are not registered nor reported. Therefore, they are never highlighted nor completely solved.

The mapping of the order process revealed several manual work steps. Interviews and results from PPM measurements in chapter 6.2.1 indicate sensitivity in the order process, since no automatic control is performed. The thesis authors would like to encourage the supplier to investigate the possibility to diminish or eliminate the manual work steps in order to secure the order process.

Even though flaws in the supplier’s internal work with product documentation could be observed, the thesis authors did not consider it a cause of the current quality level. This is because IKEA requirements are new and not fully developed. However, the supplier should consider improving the internal work in the future, since the IKEA product documentation is expected to be improved.

Since the supplier is only producing for IKEA, a clear vision for the future is missing. Consequently, the supplier will not make a bigger effort within quality work than stated in IKEA requirements, implying that quality development and improvement are strongly related to IKEA requirements. This demonstrates the importance of well-structured documented requirements and an ongoing dialog in order to develop the supplier further.

6.2.5 The CBD model

The data used in the CBD model were collected from different sources throughout the master thesis, shown in Table 6-2. Data which the supplier could not or would not provide were collected using other sources.

Cost parameters	Source
Tool cost, k_A	Authors' estimation
Material cost, k_B	Supplier
Machine cost, k_{CP}, k_{CS}	IKEA estimation
Wage cost, k_D	IKEA estimation
Claim penalty cost, k_{CL}	IKEA

Process parameters	Source
Cycle time, t_0	Observations
Setup time, T_{SU}	Observations
Time window production time, $T_{P,tw}$	PPM
Degree of utilization, U_{RB}	Supplier
Time window batch size, $N_{0,tw}$	Supplier
Orders, $N_{orders,tw}$	Calculated
Single batch size, N_0	Set to 1

Performance parameters	Source
Material wastage, q_B	Supplier
Rejection rate, q_Q	PPM
Downtime ratio, q_S	Calculated
Rate of re-work, q_{RW}	PPM
q_{CL}	IKEA/Supplier
$q_{CL\%}$	IKEA/Supplier

Table 6-2: Input data for parameters at Danform (Möller & Sahleström, 2011).

Tool costs were used for manual work stations, where new tools were expected to be purchased every half year. Material costs include purchase price and transportation costs from the sub-supplier to the supplier. Investment, renovation, facility and variable costs for machines were estimated together with IKEA personnel. Since regular maintenance is usually performed by the operators, hourly maintenance costs were set to the hourly wage cost. Wage costs for operators were estimated by IKEA personnel.

6.2.5.1 CBD model as a single unit approach

Figure 6-17 contains the supplier's cost structure of the four laminate worktops, chosen in chapter 5.1.3. The affecting cost and process parameters regarding claims are not part of the cost structure of specific worktops and are therefore not shown. Figure 6-17 indicates that the material cost has the highest effect of the total cost, which constitutes of more than 50 % of the total cost in all four cases. The material cost of case 3 also includes the material cost of the sink. Machine production costs increases with longer cycle times of machine processes, and vary between 10-12 % of the total cost. Machine downtime cost varies between 3-4 % of the total cost. The wage cost increases with longer cycle time, regarding machine processes and especially regarding manual work stations. Wage cost varies between 12-28 % of the total cost. Tool costs are negligible.

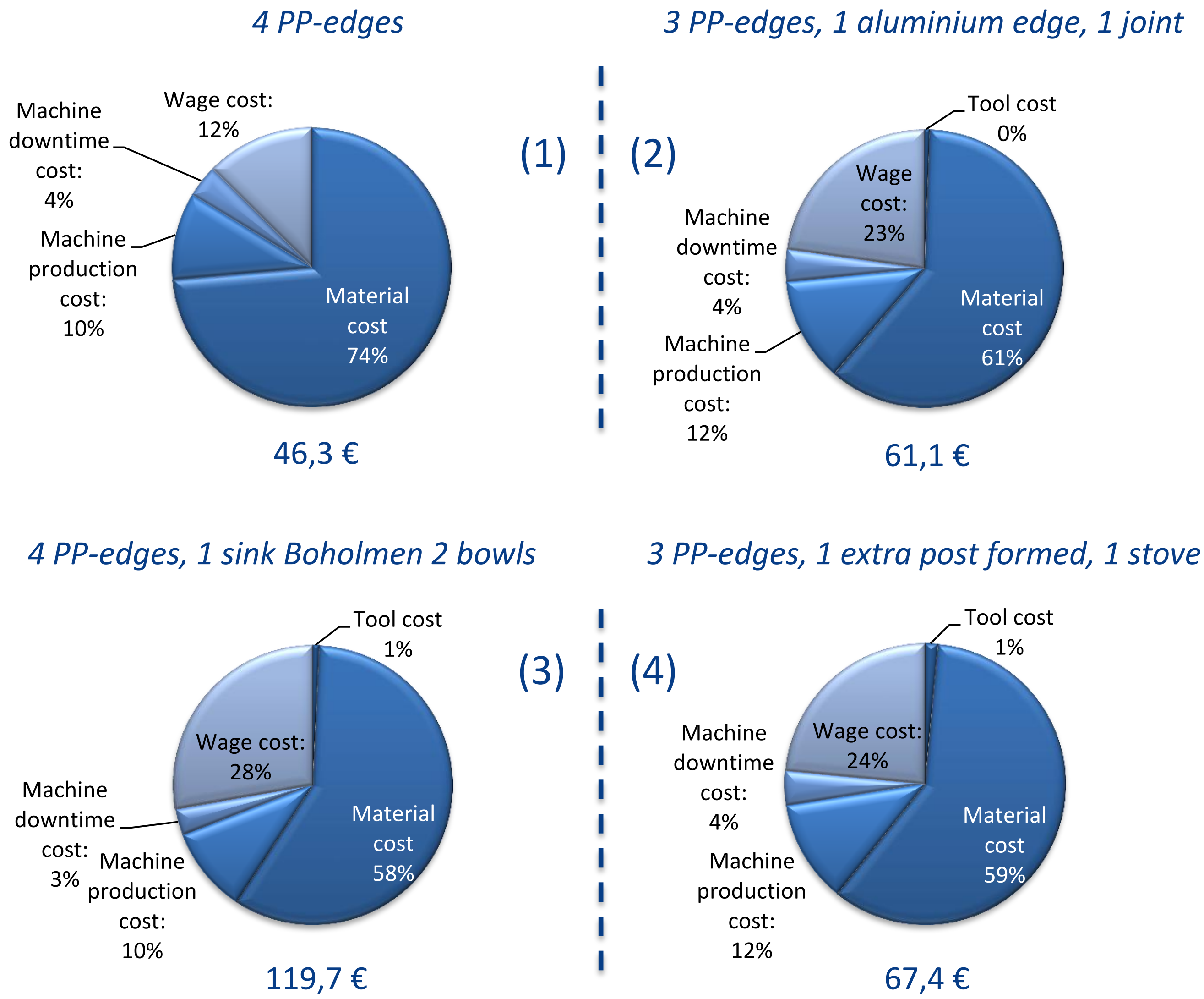

Figure 6-17: CBD of four laminate worktops (Möller & Sahleström, 2011).

6.2.5.2 CBD model as a system approach

Due to the production flows at the supplier, the following estimations were made in order to calculate the cost of the average PERSONLIG worktop:

- Since IKEA and the supplier do not agree upon the actual claim rate, both the claim rate according to IKEA and the supplier are used, as stated in chapter 4.1.2.2.

Figure 6-18 demonstrates two cost structure scenarios of the average PERSONLIG worktop. The figure indicates that the material cost constitutes the major cost of the average laminate worktop. The wage cost has the second largest cost effect and makes up almost a fourth of the total manufacturing cost. The total machine cost corresponds to 14 % and the tool costs are negligible. The claim penalty cost varies between 3-7 % of the total cost, depending on the percentage of claimed orders.

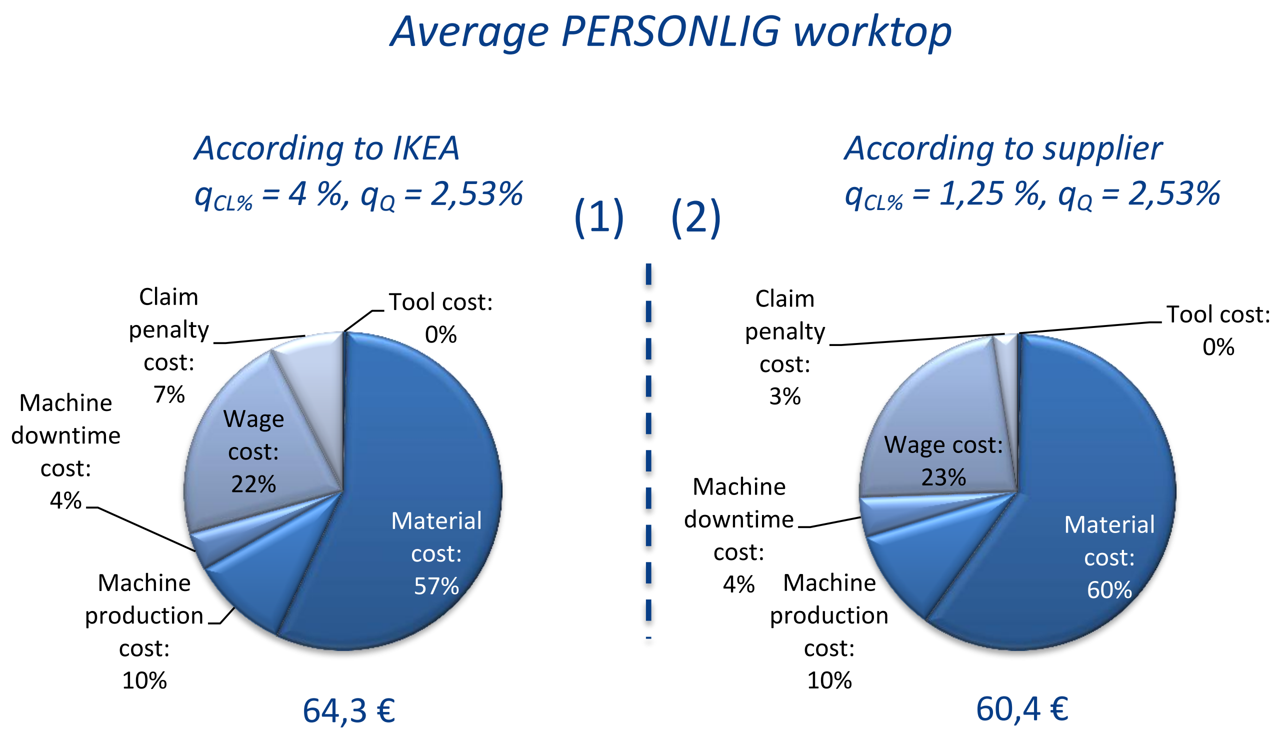

Figure 6-18: CBD of the average PERSONLIG worktop (Möller & Sahleström, 2011).

The annual economic effect of root-cause preventions are calculated by multiplying the yearly amount of worktops produced with the manufacturing cost of the average PERSONLIG worktop at the supplier, then adjusting the performance parameters regarding quality, which is claim rate and rejection rate. Decreasing claims and rejections, due the execution of root-cause preventive actions, results in a lower average PERSONLIG worktop cost, implying a cost savings potential. The supplier produces in average 190 000 PERSONLIG worktops yearly. The cost savings are presented in chapter 7.2.3.

7 Results and conclusions

In this chapter, the key questions stated in the problem descriptions will be answered, by drawing conclusions from the analysis.

It must be stressed that the root-causes of poor quality at the suppliers can not be considered as isolated events, which can be eliminated one by one. The root-causes identified are interdepended from a holistic perspective; a perspective that both suppliers are missing. The preventive actions presented for each supplier is a complete action plan based upon the supplier's root-causes. The preventive actions will be explained by using the repetitive process illustrated in Figure 7-1, giving a better understanding of the interdependent relationships of the root-causes. The model in Figure 7-1 is based on the Six Sigma DMAIC-model described in chapter 3.1.5. Communication is placed in the center of the model to better illustrate that each step involves different departments and participants, and their coordination is important in order to maintain a holistic perspective.

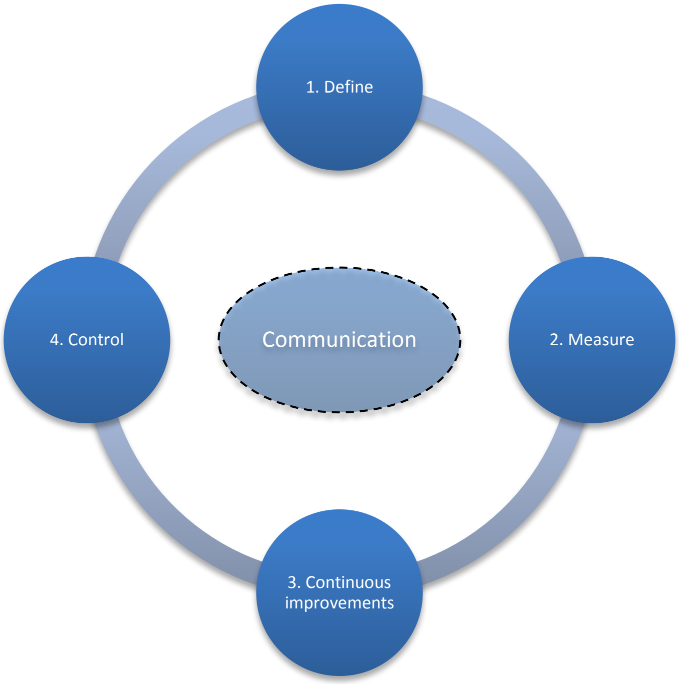

Figure 7-1: The repetitive process in which the results are presented (Möller & Sahleström, 2011).

7.1 Lechner

7.1.1 Root-causes of poor quality

The five root-causes of poor quality at the supplier are described below. The thesis authors conclude that the major root-causes of poor quality are that the supplier:

- ***Does not work with operator involvement***

The analysis shows that operator involvement regarding quality is almost inexistent. This is due to the absence of improvement and follow-up meetings, lack of communication channels, focus on production rate rather that quality improvements as well as absence of both stated quality control responsibility and quality improvement responsibility on the shop floor.

- ***Does not have a measurement system supporting continuous improvements***

The analysis shows that in the measurement system, it is not possible to connect a quality parameter with neither a cause nor a work station. The measurement system has a shortage of quality parameters of choice and operators have no responsibility of transferring their knowledge to the measurement system. Process control is lacking, both regarding execution and registration of data.

- ***Does not have a structured and coordinated cooperation between departments***

The analysis shows that the engineering department works with improvement projects and the quality departments with quality structure; the communication between these two departments is inadequate. Single projects that should involve more departments are performed without coordination, and communication regarding quality issues with other related departments is lacking.

- ***Does not work with structured control through documentation***

The analysis shows that no production processes are mapped and documented. There is neither clear process ownership nor process supervising within production activities. There are no documented CTQ parameters and no clear statements regarding product quality control or process control. This makes follow-ups and internal audits hard to execute. Furthermore, the supplier has no quality system.

- ***Has an absence of management commitment to quality***

The analysis shows that quality is not a prioritized question for management. This is reflected in answers and discussions throughout the master thesis, as well as in the four above identified root-causes.

7.1.2 Preventive actions

The expectation of the thesis authors is that this master thesis shall serve as a preventive action in order to increase management commitment to quality.

7.1.2.1 Define (1)

Firstly, production processes and work station activities must be mapped and documented. Each process is assigned to a process owner, responsible for the process improvement, and a process supervisor, responsible for the correct process execution. Also, quality responsibility of all personnel must be stated. Secondly, product and process CTQ parameters must be identified, documented and communicated. The

CTQ parameters must be based upon customer requirements. Furthermore, together with agreed tolerances, it must be stated how, how often and where the CTQ parameters are to be measured and controlled. Also, quality goals and KPI parameters must be established. At the end of this phase, well-documented instructions must be placed at each work station, clearly highlighting the CTQ parameters of the activity. This should be a foundation of a QMS.

7.1.2.2 Measure (2)

When stated how, how often and where to measure CTQ parameters, a measurement system must be developed to support the usage of continuous improvements. By implementing a sufficient amount of quality parameters connected to rejection causes and work stations, the measurement system will capture the knowledge of the operators and provide high quality data for improvements. Follow-ups must be performed in order to secure data validation. Also, process measurements should be performed at feasible work stations and the results registered in order to be evaluated by the responsible department.

7.1.2.3 Continuous improvements (3)

Quality responsibility has been stated in the define phase. However, it is also essential to add operator involvement and operator responsibility to continuously improve the production. One example would be to introduce improvement meetings with pre-specified agendas within feasible time frames, where divisions of the production come together in groups, discussing e.g. issues occurred during the time frame, which issues have been solved on the shop floor and which require attention from departments. Also, this would be an excellent forum for departments to share measurement results and future projects to operators. These meetings states as one example of how to add direct communication channels between the shop floor and departments.

Work regarding continuous improvements involves several departments, between which cooperation and coordination must be improved. As similar to the above example, meetings within certain time frames should be settled in order to establish a shared quality action plan, discussing projects and prioritizing efforts and resources.

7.1.2.4 Control (4)

When processes are stated in written form, follow-ups and internal audits will be possible to execute in order to ensure process performances and to implement improvements of work methods.

7.1.3 Economic effect of root-cause preventions

Since the root-causes of poor quality are not isolated events, no single preventive action can be ascribed a specific economic effect. The cost savings are therefore calculated from a holistic perspective based upon a decrease in claim rate and rejection rate, rather than a segmentation of preventive actions. The calculations are described in chapter 6.1.5.1.

Since no unequivocal claim rate is determined, two cost savings scenarios are presented; one according to IKEA and one according to the supplier. Thus giving an interval of the potential supplier manufacturing cost savings, presented in Figure 7-2.

If the mentioned preventive actions are executed, the thesis authors state the hypothesis that the claim rate and rejection rate will decrease. However, the thesis authors can not state that neither the claim rate nor the rejection rate will decrease to 0 %. External factors may still affect the claim rate, and claims can incorrectly be ascribed to the supplier. Therefore, the thesis authors consider a 0 % claim rate of today to be implausible. In the two scenarios, the first scenario displays a decrease in claim rate with 50 % and the second scenario a decreased claim rate down to 1 %, which the thesis authors have estimated plausible.

The presented root-cause preventions result in a feasibility of decreasing the rejection rate with 50 %, equal to 1 percentage point. However, due to the complexity and flexibility of the customized production, the thesis authors can not state the plausibility of decreasing the rejection rate with 100 %.

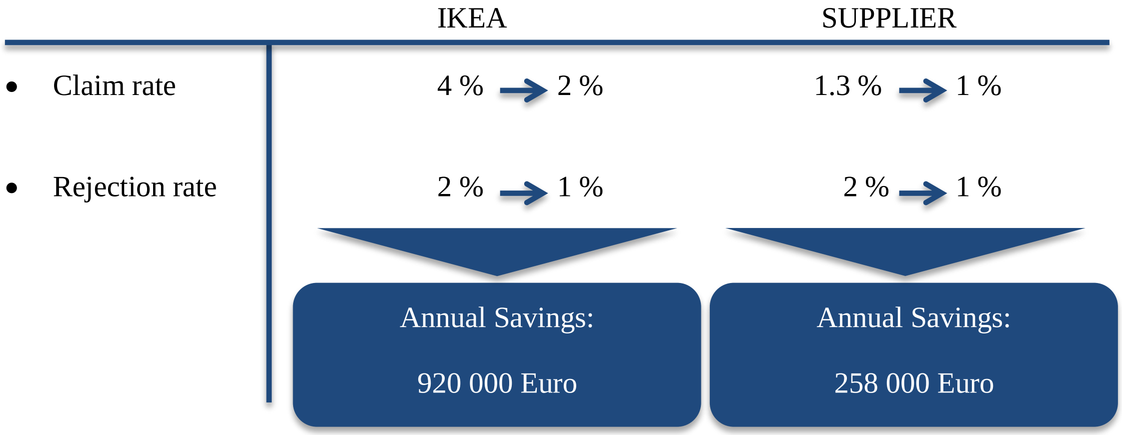

Figure 7-2: Economic effect of prevented root-causes at the supplier (Möller & Sahleström, 2011).

7.1.4 Cost structure

As seen in chapter 6.1.5.1, each worktop has a unique cost structure depending on the chosen variables. However, it is clearly shown that material cost has the biggest impact on total manufacturing cost, regardless of variables chosen in all worktop cases. It is also shown that material cost and wage cost always compose of more than 75 % of total manufacturing cost. The cost structure reflects a versatile production, where manual processes have bigger impact on manufacturing cost than machine processes.

7.2 Danform

7.2.1 Root-causes to poor quality

The three root-causes of poor quality at the supplier are described below. The thesis authors conclude that the major root-causes of poor quality are that the supplier:

- ***Does not work with operator involvement***

The analysis shows that the operator involvement is insufficient. This is due to the absence of improvement and follow-up meetings, lack of information and data sharing to operators and utilization of the operators' gathered knowledge.

- ***Has an insufficient method of product control***

The analysis shows that product quality control at work stations is not fully performed according to work descriptions and the current quality approach is neither communicated to the shop floor nor constructed from a holistic perspective. There is a lack of feasible quality control conditions at work stations and the product quality control at the final inspection does not meet the requirements of the 8 GO/NO GO in the IKEA SQS.

- ***Has a weak structure of quality work regarding continuous improvements***

The analysis shows that the supplier neither has a comprehensive view nor coordination of quality work and that quality work is only performed within the manufacturing, where chronic problems are accepted. The measurement system has both weak information structure and information quality and should be further developed in order to support continuous improvements. The management handbook does not contain quantified goals or KPI parameters related to product quality, there is a lack of project structure and project approach towards continuous improvements, and there is no one responsible for the task of executing improvement projects.

7.2.2 Preventive actions

7.2.2.1 Define (1)

Firstly, where, how and how often to measure product quality must be stated from a holistic perspective if the supplier approach towards quality control is to be maintained. This perspective must be spread to the shop floor in order to ensure 100 % clarification of quality control responsibility, and the appropriate control conditions at each work station must be provided. The role of the final inspections should be further discussed with IKEA. State a person responsible for coordination of the company's comprehensive quality work, as well as responsible for executing projects within continuous improvements.

The management handbook must have quantified product quality goals, translated into KPI parameters, and should also be complemented with project structure standardization. This would make up a stronger foundation for a QMS and continuous improvements.

7.2.2.2 Measure (2)

Improve the measurement system regarding information structure and information quality, eliminating variations of reporting by using only one name per work station and applying the concept of connecting cause and effect for all rejections. Create instructions of how to report rejections to the production leader, encourage operators to follow these instructions and communicate the importance of correct reporting.

7.2.2.3 Continuous improvements (3)

Implement regular improvement and follow-up meetings on the shop floor with pre-specified agendas within feasible time frames, where the production come together, discussing e.g. issues occurred during the time frame and which issues that need attention from other departments. Highlight and document the occurrence of chronic problems as well as utilize operators' gathered knowledge to solve these. Also, this would be an excellent forum to share measurement results and future projects to operators.

Define sub-goals based upon the quality goals in the management handbook in order to identify and execute feasible smaller improvement projects measureable in KPI parameters, using the project structure from the define phase.

7.2.2.4 Control (4)

Follow up of the holistic quality approach, described in the define phase. Update the management handbook regarding improvement projects in order to secure sustainable solutions.

7.2.3 Economic effect of root-cause preventions

Since the root-causes of poor quality are not isolated events, no single preventive action can be ascribed a specific economic effect. The cost savings are therefore calculated from a holistic perspective based upon a decrease in claim rate and rejection rate, rather than a segmentation of preventive actions. The calculations are described in chapter 6.2.5.1.

Since no unequivocal claim rate is determined, two cost savings scenarios are presented; one according to IKEA and one according to the supplier. Thus giving an interval of the potential supplier manufacturing cost savings, presented in Figure 7-3.

If the mentioned preventive actions are executed, the thesis authors state the hypothesis that the claim rate and rejection rate will decrease. However, the thesis authors can not state that neither the claim rate nor the rejection rate will decrease to 0 %. External factors may still affect the claim rate, and claims can incorrectly be ascribed to the supplier. Therefore, the thesis authors consider a 0 % claim rate of today to be implausible. In the two scenarios, the first scenario displays a decrease in claim rate with 50 % and the second scenario a decreased claim rate down to 1 %, which the thesis authors have estimated plausible.

The presented root-cause preventions result in a feasibility of decreasing the rejection rate with 40 %, equal to 1 percentage point. However, due to the complexity and flexibility of the customized production, the thesis authors can not state the plausibility of decreasing the rejection rate with 100 %.

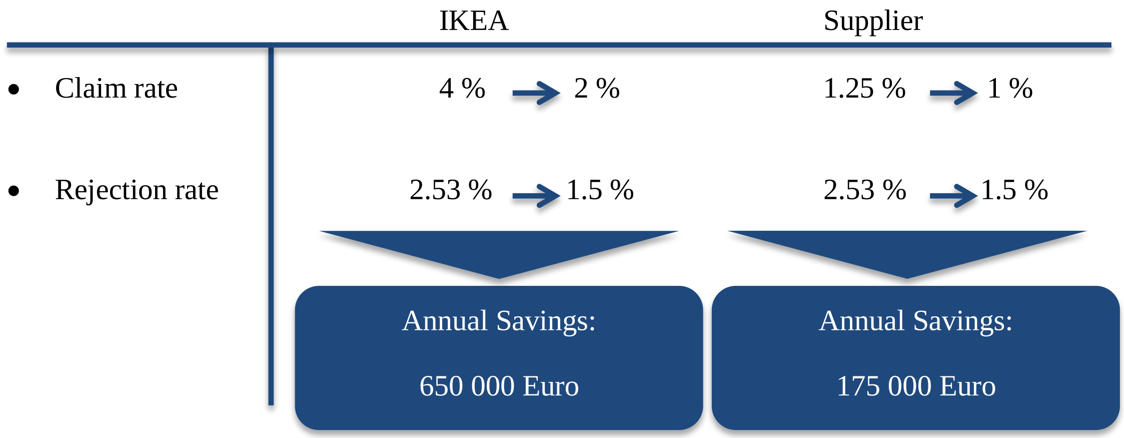

Figure 7-3: Economic effect of prevented root-causes at the supplier (Möller & Sahleström, 2011).

7.2.4 Cost structure

As seen in chapter 6.2.5.1, each worktop has a unique cost structure depending on the chosen variables However, it is clearly shown that material cost has the biggest impact on total manufacturing cost, regardless of variables chosen in all worktop cases. It is also shown that material cost and wage cost always compose of more than 80 % of total manufacturing cost. The cost structure reflects a versatile production, where manual processes have bigger impact on manufacturing cost than machine processes.

8 Discussion

In this chapter, the master thesis participants are encouraged to take specific actions, discussing areas of improvements and further investigations. The quality of the master thesis is also discussed.

This master thesis has aimed to answer the three key questions stated in the problem description. The root-causes of poor quality have been identified from a holistic perspective, specific preventive actions have been stated and the economic effect of root-cause preventions has been constructed as cost savings intervals. Also, the economic cost structure of worktop cases has been presented.

The thesis authors would like to encourage the suppliers to take the identified root-causes and preventive actions into account when forming strategies for the future. The findings show a substantial cost savings potential, although only including the manufacturing cost. When also considering the remaining traditional costs, as well as hidden costs and lost sales, the saving potential increases even further. The preventive actions have been adapted to the capability and organizational structure of each supplier, ensuring both usability and suitability. For greater understandability, the preventive actions have been presented from a holistic perspective, with focus on areas where they can be used efficiently.

The validity of the master thesis can be considered fair since the demonstrated root-causes of poor quality are delimited to the supplier facilities, where also the gathering of supplier information has been performed. The large number of interviews and the work task variety of the respondents, together with the implementation of PPM measurements, the use of well-known and well-functioning quality theories as well as the application of a new manufacturing cost model also strengthen the validity of the master thesis.

The reliability of the master thesis can be considered as satisfying, due to the combination of many fields and sources of data, explained in chapter 2.2. The results of repeated PPM measurements would have varied, due to the single-unit production setup as well as the flexibility within the manufacturing. The circumstances that occurred during the PPM measurements, e.g. some inadequate and incorrect registration of rejections, had a logic effect on the final result. Flaws in the PPM measurements reflect weaknesses within the suppliers' work methods. These weaknesses were further analyzed and translated into identified root-causes. Consequently, the flaws in the PPM measurements have affected the final result as it displayed the true situation at the suppliers. Therefore, the reliability of the master thesis is trustworthy.

Due to further investigations through interviews and observations, the large amount of quality parameters registered as "Übriges" did not affect the reliability of the master thesis. Nonetheless, an introduction of PPM measurements at the suppliers would require more quality parameters in order to decrease this amount.

The delimitations, explained in chapter 1.3, have influenced the results of the master thesis in different ways. Firstly, since external factors outside supplier facilities were not examined, a complete supply chain analysis has not been performed. However, this has not affected the identified root-causes of poor quality at the suppliers, but implies that neither the complete cost savings throughout the supply chain nor the exact cost savings at the suppliers could be examined. Also, the suppliers' total contribution to poor quality within the supply chain could not be determined. Secondly, the delimitation of materials has affected the project structure, however not the results, since the drawn conclusions are on a holistic level and should be applicable to all materials at each supplier. Thirdly, the thesis authors have tried to sustain an objective perspective by making no comparison between the suppliers. Therefore, the suppliers have been treated as two separate cases with individual, non-generic results and conclusions.

For further improvements, the thesis authors would like to recommend IKEA to investigate the claim process. IKEA has not succeeded to agree upon an official claim rate with neither of the suppliers, which decreases supplier motivation to take actions and obstructs the possibility of responding to failures. In order to increase customer satisfaction and support quality improvements within the PERSONLIG range, IKEA should develop a standardized, reliable and real-time reporting claim process together with the suppliers. This is the most crucial improvement that IKEA can perform in order to help the suppliers with their quality work.

IKEA is also encouraged to examine the procedure of callbacks. A standardized and fast process would most probably increase customer satisfaction and facilitate the order process at the suppliers. Furthermore, due to the vast experience at IKEA within handling of product documentation and CTQ translation, IKEA has a great opportunity to spread this knowledge to the suppliers in order to assist their quality work.

Moreover, the thesis authors claim that further investigations regarding the corresponded risks and opportunities within the economic cost structure of the product, optimization of production layouts and lead-times as well as production economic analysis inspecting impact of cost drivers could be of interest, improving the suppliers further.

9 Contribution to academia

In this chapter, the master thesis presents the contributions made for academic and research purposes. This chapter concludes the master thesis.

There are numerous quality theories, and the master thesis combines thoughts and frameworks from different sources. The presented solutions for quality improvements are based on quality management and applied on two cases within customized production. The solutions could most probably be applied in other industries where customized production is executed. However, since the solutions are developed through case studies, and not with the purpose of being generic, the thesis authors encourage other researchers to investigate this matter further.

The manufacturing cost model used in the master thesis has been further modified by the thesis authors in order to be applied on single-unit production setups, using two different approaches. The first approach implies performance of cost calculations on individual production flows. With the second approach, the thesis authors have shown that, by using a control volume as a planning point, the cost model can be applicable on a manufacturing system. This approach renders the possibility to calculate the average manufacturing cost within customized production. It also allows for comparison and evaluation of cost savings of different improvement projects and could help customized producers to prioritize necessary actions within production development. Though, since no assessment has been made regarding the implementation of TEV as a KPI within customized production, the thesis authors encourage further research within the area.

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10.4 Internal material

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Management handbuch, Danform, Änd.Stand 3/11

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German claim statistics 2011, IKEA

Claim statistics 2010 & 2011, Lechner

Claim statistics 2010 & 2011, Danform

10.5 Interviews

10.5.1 IKEA

Elfving, Peder - Deputy Trading Area Manager
Huber, Peter - Business Development Manager
Jacobs, Heiko - Business Developer
Jacques, Stéphane - Business Analyst
Johansson, Roger - Production Developer
Koch, Daniel - Technician
Lange, Uwe - Business Development Manager
Meyer, Jürgen - Technician

10.5.2 Lechner

Beyl, Thomas - CEO, Finance and HR
Geber, Sven - Shift Leader Manager
Grünhage, Timo - Quality Department
Kohler; Helmut - Purchase Department
Nöhring, Torsten - Quality Department
Pfeiffer, Markus - Industrial Engineering Department
Quapil, Günter - IKEA Documentation
Schauer, Ralph - Industrial Engineering Department
Schmutzler, Andreas - CEO, Technical Manager
Seiss, Birgit - Order Department, Sachbearbeiterin
Veit, Reiner - Industrial Engineering Department
Wengertsmann, Martin - Industrial Engineering Department
Wörner, Tina - Key Account Manager IKEA
18 production operators

10.5.3 Danform

Batke, Matthias - Order Department, Sachbearbeiter
Bröker, Denise - Management Assistant
Buschwald, Falk - Quality Department, Quality Responsible
Danielmeyer, Rainer - CEO
Elste, Guido - Production Leader
Fischer, Ulrike - Order Department, Sachbearbeiterin
Grote, Fritz - Purchasing Manager
Isenbart, Marcus - Production Manager
Scharf, Julia - Order Department, Sachbearbeiterin
20 production operators

10.6 Abbreviations and definitions

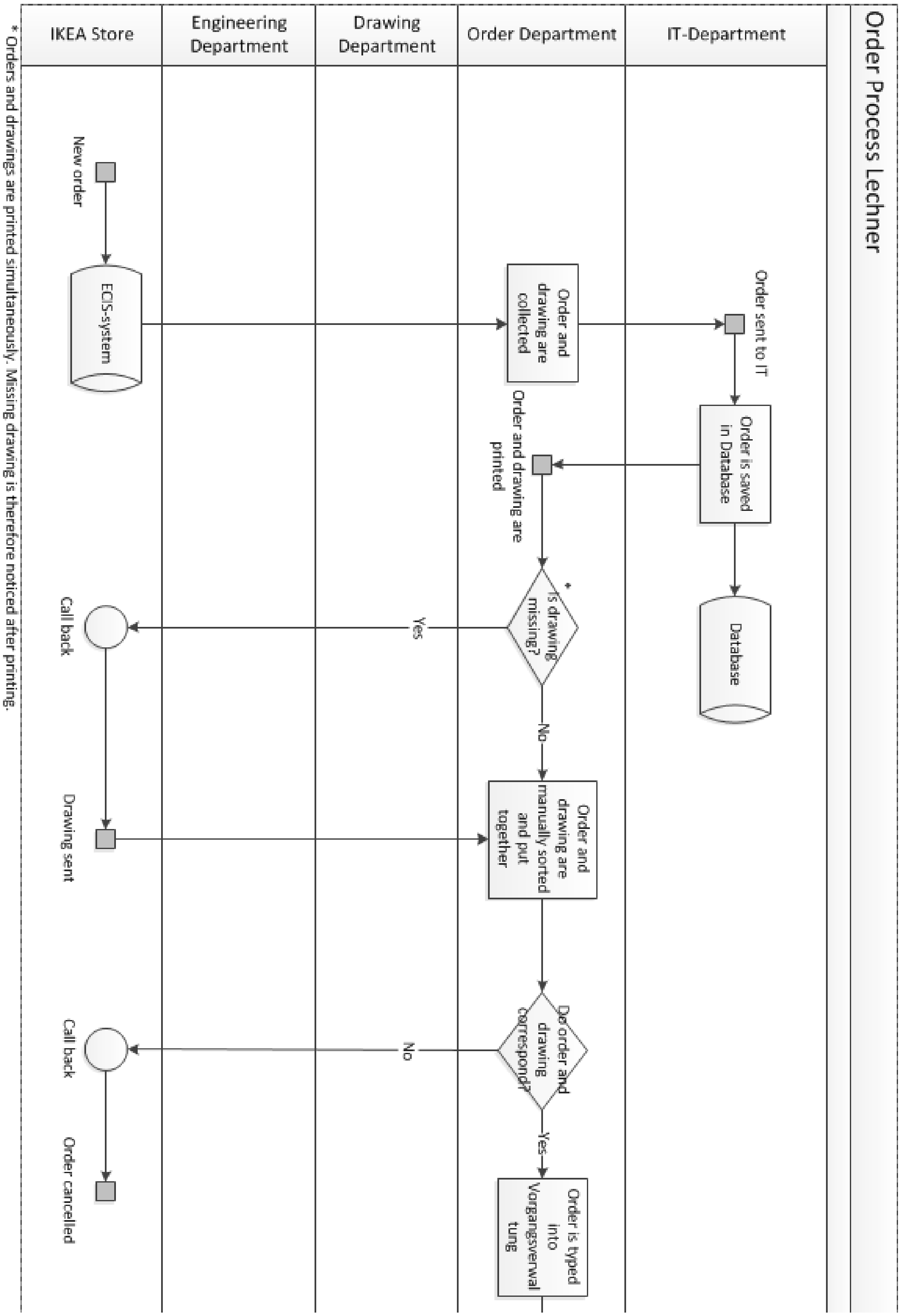
BTO - Build To Order
CBD - Cost Break Down
CCR - Critical Customer Requirements
CDC - Central Distribution Center
CEPQ - Customer Experienced Product Quality
COPQ - Cost Of Poor Quality
CTP - Critical To Processes
CTQ - Critical To Quality
DP - Differentiation Point
ERP-System - Enterprise Resource Planning System
FMEA - Failure Mode and Effect Analysis
IKEA - Ingvar Kamprad Elmtaryd Aggunaryd
IKEA IWAY - IKEA Code of Conduct towards suppliers
IKEA SQS - IKEA Supplier Quality Standard
IOS - IKEA Of Sweden
LSC - Local Service Center
MTO - Make To Order
MOSC - Make To Order Supply Chain
MSA - Measurement System Analysis
PDOC - Product Documentation System
POC - Point Of Cause
PPC - Production Planning and Control
PPM - Production Performance Matrix
QMS - Quality Management System
SCDP - Supply Chain Decoupling Point
SCM - Supply Chain Management
SPA - Systematic Production Analysis
TEV - TillverkningsEkonomisk Verkningsgrad/ Manufacturing-Economic Efficiency
TSCM - Traditional Supply Chain Management
TQM - Total Quality Management
VMI - Vendor Managed Inventory
VOC - Voice Of the Customer

10.7 German – English dictionary

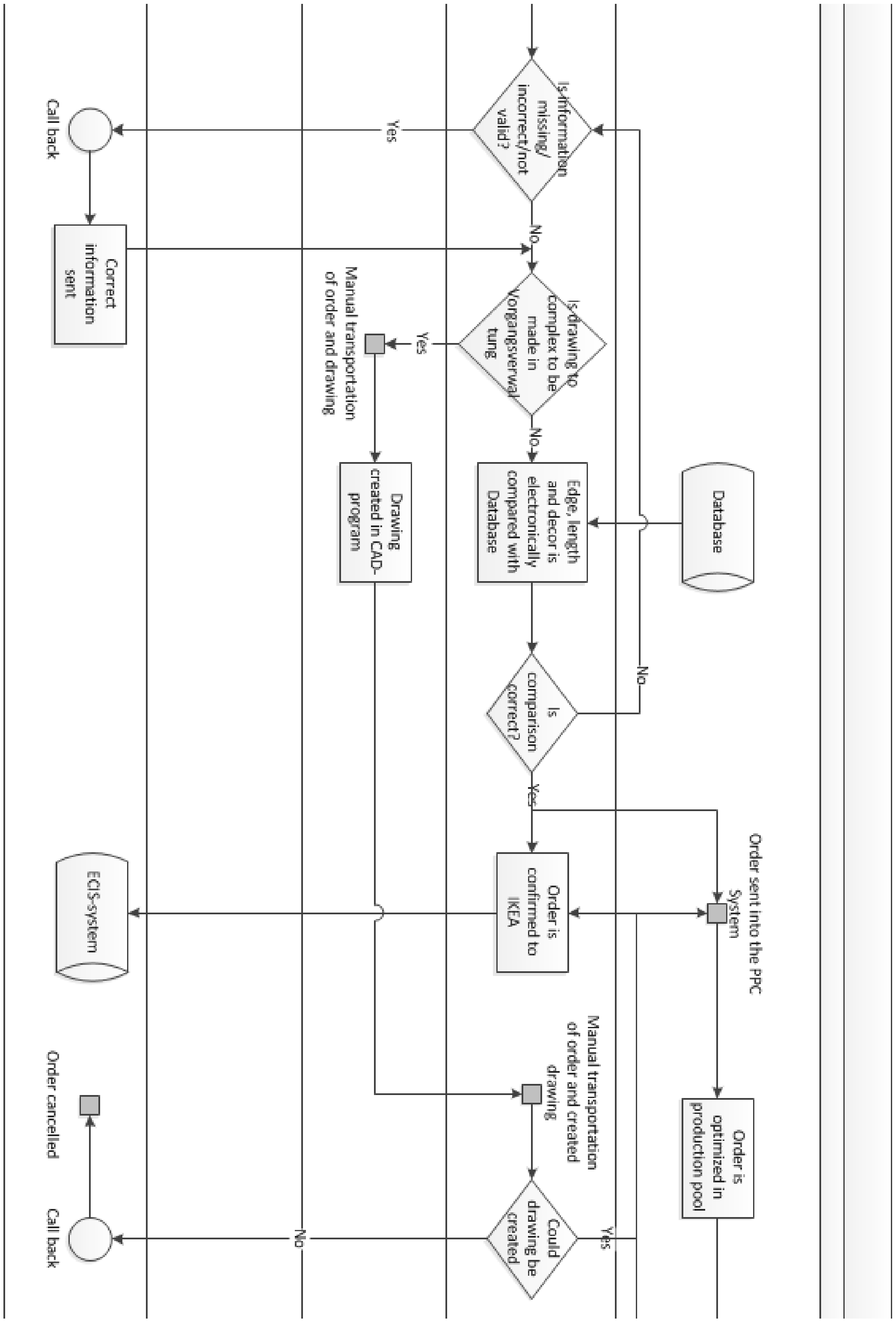
Andere Faktoren	–	Other factors
Arbeitsanweisung	–	Errors due to mistakes in work descriptions
Ausschuss	–	Rejection
AV-Fehler	–	Errors within order process
Beschädigung durch Stapler	–	Damage by forklift
Datum	–	Date
Dekor Falsch	–	Wrong laminate decor
Dekorfehler	–	Error in laminate decor
Delle/Pickel	–	Dent/Spot in laminate
Enkleber system	–	Danform's order receiving system
Fräsenfehler	–	Milling error
Kante Ausbruch	–	Break out on edge
Kante Eindruck	–	Impact on edge
Kante Kratzer	–	Scratch on edge
Kante Riss	–	Crack in edge
Maschine- & Werkzeughavarie	–	Machine & Tool Damage
Maschine	–	Machine
Maßfehler	–	Measurement error
Massivholzplatte schlecht	–	Poor quality of solid wood board
Materialfehler	–	Errors in working material
Mitarbeiterfehler	–	Errors by operator
N+F Fehler	–	Joint error
Nacharbeit	–	Re-work
Oberfläche Ausbruch	–	Break out on surface
Oberfläche Eindruck	–	Impact on surface
Oberfläche Kratzer	–	Scratch on surface
Platte Verschoben	–	Worktop displaced during processing
Post formed Konstruktionsfehler	–	Post formed construction error
PP-Kante zu kurz	–	PP-edge too short
Programmierungsfehler	–	Programming error
Schichtnummer	–	Shift number
Spanplatte schlecht	–	Poor quality of chipboard
Spüleneinbaufehler	–	Error in procedure of building-in sinks
Stossfehler	–	Joint error
Transportband/Transport	–	Conveyer belt/Transport
Übriges	–	Remaining quality parameters
Undefinierte Faktoren	–	Unknown factor
Ursache	–	Cause
Versiegelung schlecht	–	Poor quality of laminate sealing
Vorgangsverwaltung	–	Lechner's order receiving system
Werkzeug	–	Tool
Winkelfehler	–	Angle error

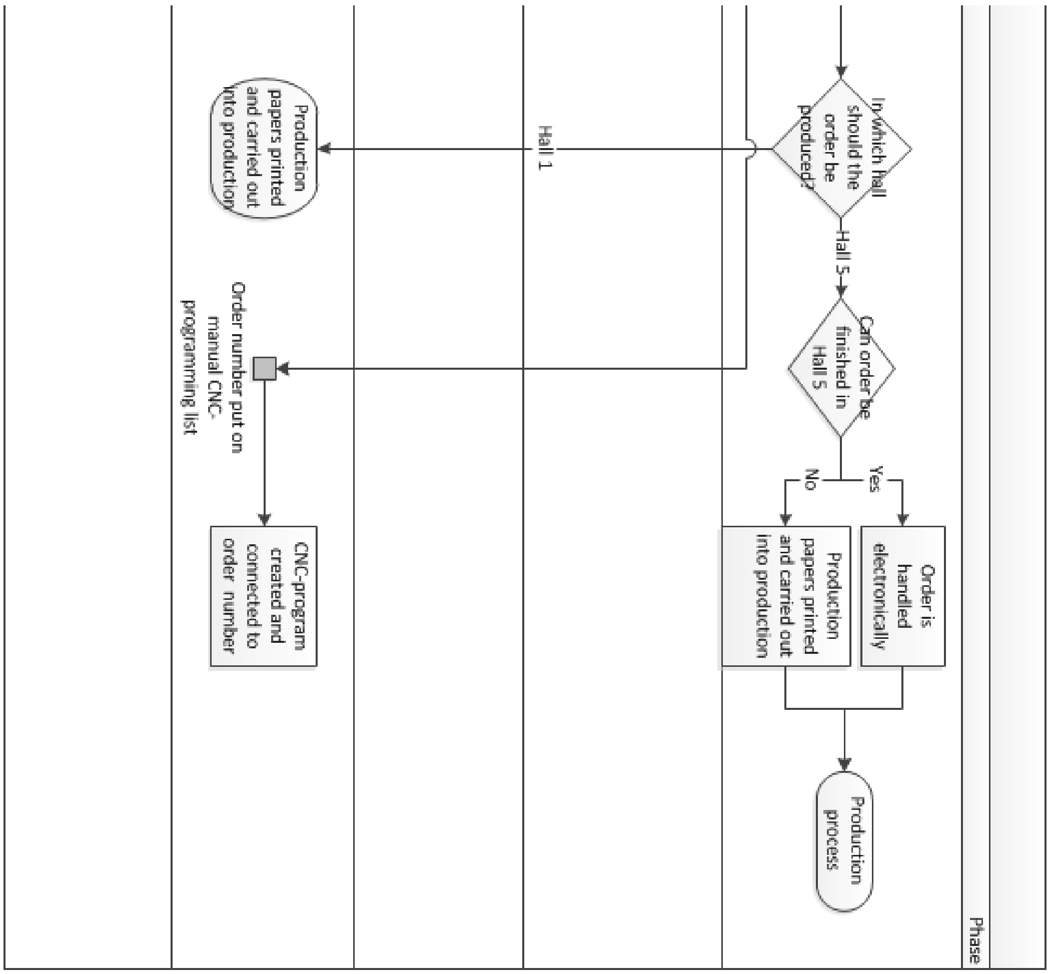
Appendix 1

Order Process – Lechner

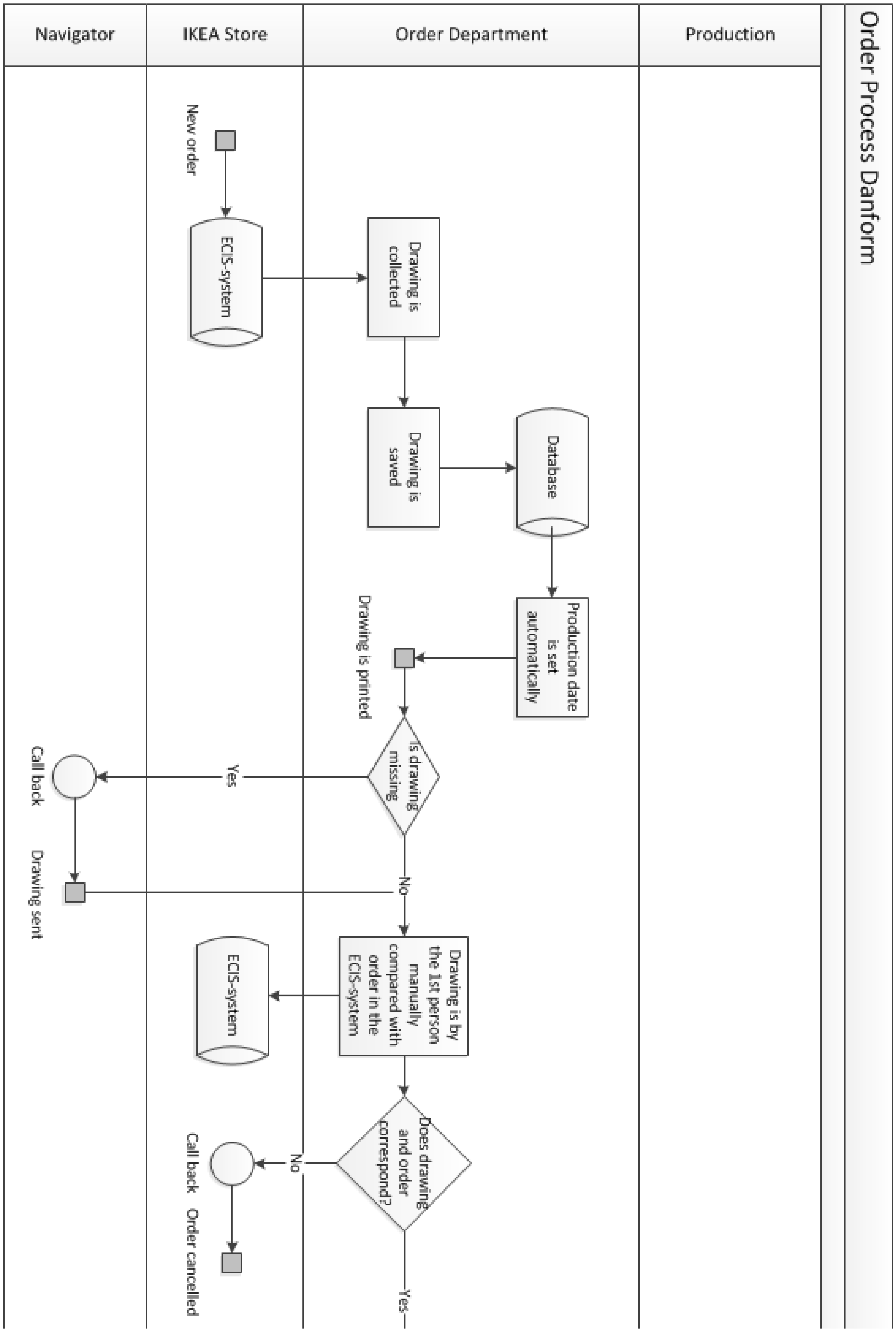


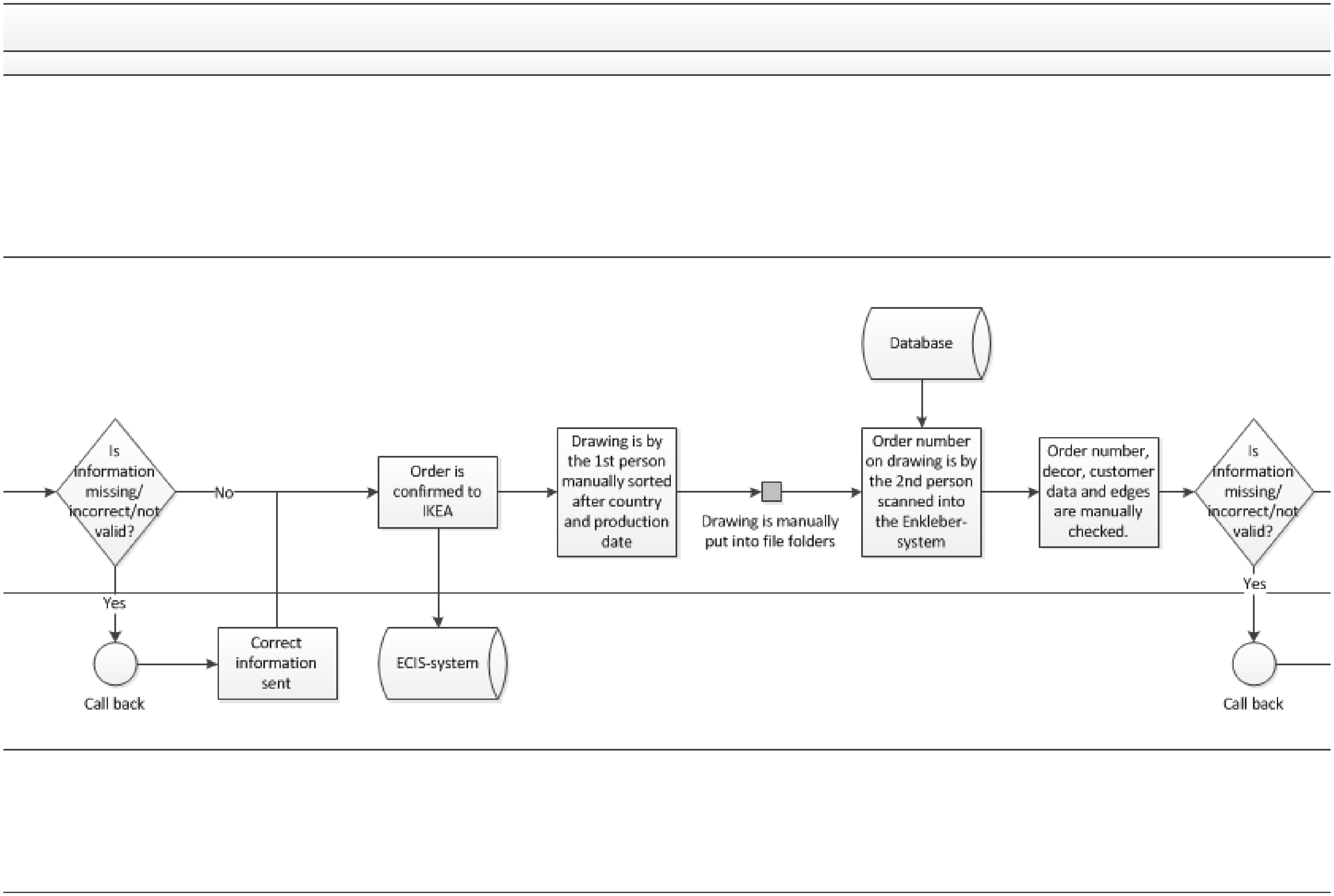
* Orders and drawings are printed simultaneously. Missing drawing is therefore noticed after printing.

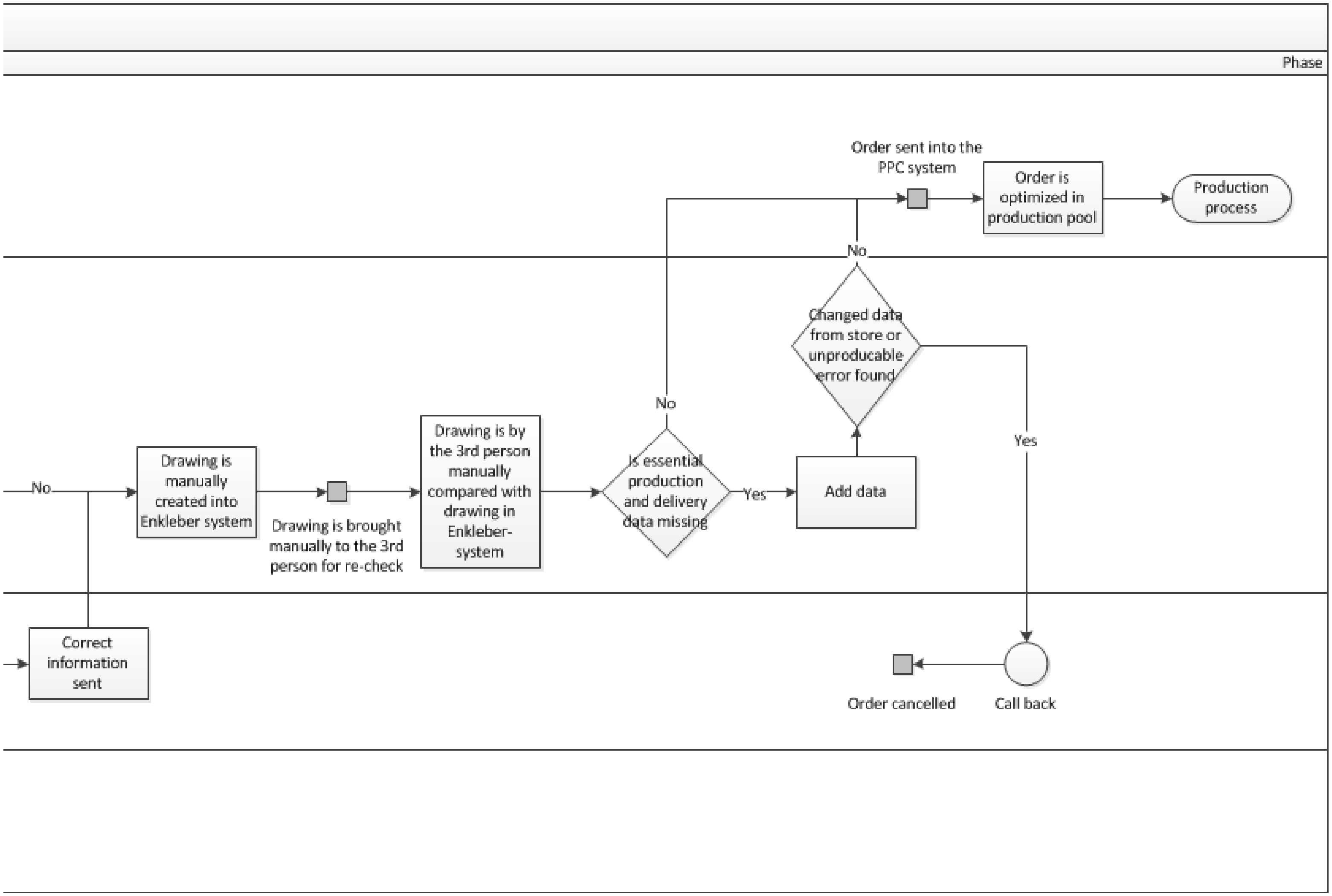

Is information missing/ incorrect/not valid?
Yes
No
Call back
Correct information sent
Is drawing to complex to be made in Vorgangsverwaltung
Yes
No
Manual transportation of order and drawing
Drawing created in CAD-program
Database
Edge, length and decor is electronically compared with Database
Is comparison correct?
No
Yes
Order sent into the PPC System
Order is confirmed to IKEA
ECIS-system
Order is optimized in production pool
Manual transportation of order and created drawing
Could drawing be created
Yes
No
Order cancelled
Call back


In which hall should the order be produced?
Hall 1
Hall 5
Can order be finished in Hall 5
Yes
No
Order is handled electronically
Production papers printed and carried out into production
Production process
Production papers printed and carried out into production
Order number put on manual CNC-programming list
CNC-program created and connected to order number
Phase

Order process – Danform




Is information missing/ incorrect/not valid?
No
Yes
Call back
Correct information sent
Order is confirmed to IKEA
ECIS-system
Drawing is by the 1st person manually sorted after country and production date
Drawing is manually put into file folders
Database
Order number on drawing is by the 2nd person scanned into the Enkleber-system
Order number, decor, customer data and edges are manually checked.
Is information missing/ incorrect/not valid?
Yes
Call back

Phase
Order sent into the PPC system
Order is optimized in production pool
Production process
No
Changed data from store or unproducable error found
No
Yes
No
Drawing is manually created into Enkleber system
Drawing is brought manually to the 3rd person for re-check
Drawing is by the 3rd person manually compared with drawing in Enkleber-system
Is essential production and delivery data missing
Yes
Add data
Correct information sent
Order cancelled
Call back

Appendix 2

Lechner – Production hall 1

Abaromat – Sanding machine: Milling and sanding of edges for solid wood worktops

Alukante – Manual work station: Gluing of aluminium edges

BIMA 410 – CNC machine: Milling of joints, stoves and single cuts

BIMA 610 – CNC machine: Milling of sinks and joints as well as milling of edges for smaller worktops

BIMA P480 – CNC machine: Laminate worktops: Shape milling, gluing of radial PP-edges and milling of post formed edges, and milling of joints. Solid wood worktops: Shape milling as well as milling for sinks and joints

Distribution station – Collecting station before the final inspection in order to redistribute worktops in the production for various reasons, e.g. worktops that need edge bending, sinks or re-work

Elementskante – Manual work station: Gluing of mineral edges. Not of interest in the master thesis

Endkontrolle – Final inspection station: Final inspection of worktops without built in sinks

Endkontrolle Spüle – Final inspection station: Final inspection of worktops with built-in sinks

EVK – Manual work station: Gluing of extra post formed edges

HKA Dekor – Manual work station: Gluing of PP-edges and laminate edges for worktops with single, double or triple cut. Edges must be longer than 10 centimetres. Edges shorter than 10 centimeters are sent to Nachbearbeitung.

Holzma – Automatic saw: Sawing of raw material, length and depth

Hüllhorts – Semi-automatic saw: Sawing of raw material, length and depth

Lackiererei – Manual work station: Oiling of solid wood surfaces as well as lacquering of wooden edges

Massivholz HB – Manual work station: Refinement for solid wood worktops

Nachbearbeitung/Kante AC/Holz/Dick – Manual work stations: Operators regards these work station as one work station. Performance of work that can not be performed by machine equipment as well as re-work

Novimat – Edge bending machine: Gluing of PP-edges and mineral edges.

Optimat – Edge bending machine: Gluing of laminate edges, wooden edges and smaller aluminium edges.

Presse – Press: Gluing of worktops for double thickness, 80 mm

Schichtstoffsäge – Manual saw: Mostly used for re-work and re-use

Spüleneinbau – Manual work station: Building-in sinks, both for laminate and solid wood worktops

Spülenverpackung – Packaging station: Packaging of worktops with built-in sinks

Verpackung – Packaging station: Packaging of worktops without built-in sinks

Weber Breitband – Sanding machine: Sanding of surfaces for solid wood worktops

Zusammenpassen – Manual work station: Visual and test inspection of straight and visible joints

Lechner – Production hall 5

Advantage – Edge bending machine: Gluing of laminate edges and PP-edges

Collecting Station 1 – Collecting station for worktops which can not finish production in hall 5. Distribution of worktops is performed to hall 1 to the work stations Optimat, Novimat, BIMA P480, Zusammenpassen, HKA Dekor and EVK.

Collecting Station 2 – Collecting station for worktops which can not finish production in hall 5. Distribution of worktops is performed to hall 1 to the work stations Alukante and BIMA 610.

Dekorkante Links – Edge bending machine: Gluing of PP-edges on the left side of the worktop

Dekorkante Rechts – Edge bending machine: Gluing of PP-edges on the right side of the worktop

Eckverbindungfräse I – CNC machine: Milling of joints, stoves and aluminium edges

Eckverbindungfräse II – CNC machine: Milling of joints, stoves and aluminium edges

Endkontrolle – Final inspection station: Final inspection of worktops without built-in sinks

Hinterkante: Edge bending machine: Gluing of laminate edges and PP-edges on the back side of the worktop. Only used when the backside of the worktop is sawed off and the original post formed edge on the front is kept

Holzma – Automatic saw: Sawing of raw material, length

Konturfräse I – CNC machine: Shape milling as well as edge bending for radial laminate edges

Konturfräse II – CNC machine: Shape milling, gluing of radial PP-edges and milling of post formed edges

Tiefenschnitt – Automatic saw: Sawing of raw material, depth

Verpackung – Packaging station: Packaging of worktops without built-in sinks

Danform – Production hall

Alukante – Manual work station: Gluing of aluminium edges

CNC – CNC machine: Milling of groove and tongue for worktop with joints

Endkontrolle/Verpackung – Final inspection and packaging station: Final inspection and packaging worktops

Holzkante – Manual work station: Gluing of wooden edges

IMA 410 – CNC machine: Milling of sinks, post formed edges and stoves

IMA 610 – CNC machine: Milling of aluminium edges, joints with visible connections, stoves, shape milling and gluing of radial PP-edges

Novimat 1 – Edge bending machine: Gluing of laminate edges and PP-edges

Novimat 2 – Edge bending machine: Gluing of laminate edges and PP-edges

Post formed – Manual work station: Gluing of post formed edges, smaller PP-edges

Quadromat – Unsupervised CNC machine: Milling of joint holes on the underside of the worktop

Stosskontrolle – Manual work station: Visual and test inspection of straight and visible joints

Säge 1 – Automatic saw: Sawing of raw material, length and depth

Säge 2 – Automatic saw: Sawing of raw material, length and depth

Spüleneinbau – Manual work station: Building-in and final inspection of sinks

Verteiler 3 – Automatic buffer

Verteiler 4 – Automatic buffer

Verteiler 5 – Automatic buffer

Verteiler 6 – Automatic buffer

Verteiler 7 – Automatic buffer

Appendix 3

PPM Lechner, Laminate worktops

	PPM Laminate, Hall 1 & Hall 5																					
	qQ																					
Lechner	Maßfehler	Winkelfehler	Stossfehler	Fräsenfehler	Post formed konstruktionsfehler	PP-Kante zu kurz	Alukante Verleimung nicht gut	Dekorfehler	Dekor Falsch	Kante Riss	Kante Ausbruch	Kante Eindruck	Kante Kratzer	Oberfläche Ausbruch	Oberfläche Eindruck	Oberfläche Kratzer	Versiegelung schlecht	Spanplatte schlecht	Delle/Pickel	Spüleneinbaufehler	Übriges	**Total**
Machine & Werkzeug	21	5	2					6	1	8	9	6	6	18	6	19	1		7	1	13	129
Materialfehler								14	3							3	5	3	12		2	42
Mitarbeiterfehler	1	1	1							2	2	1	1	1	1						1	12
Arbeitsanweisung																						0
Machine- & Werkzeughavarie																						0
AV-Fehler																					2	2
Transportband/Transport																						0
Beschädigung durch Stapler																						0
Andere Faktoren																						0
																						0
																						0
Undefinierte Faktoren	3																					3
Total	25	6	3	0	0	0	0	20	4	10	11	7	7	19	7	22	6	3	19	1	18	**188**

PPM Lechner, Solid wood worktops

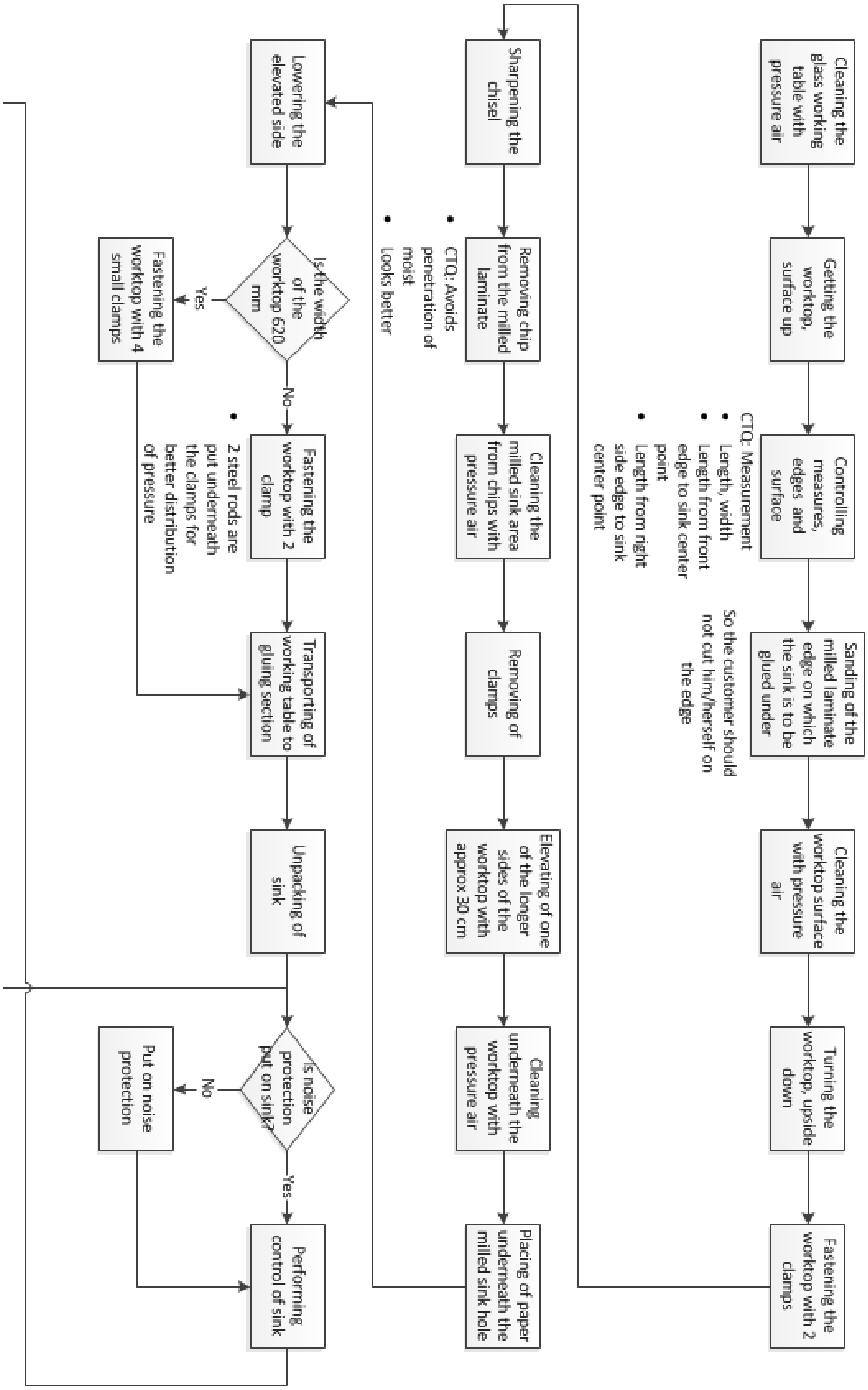
	PPM Solid wood, Hall 1														
	qQ														
Lechner	Maßfehler	Winkelfehler	Stossfehler	Fräsenfehler	Kante Riss	Kante Ausbruch	Kante Eindruck	Kante Kratzer	Oberfläche Ausbruch	Oberfläche Eindruck	Oberfläche Kratzer	Massivholzplatte schlecht	Spüleneinbaufehler	Übriges	**Total**
Machine & Werkzeug	1	2	1			1								4	9
Materialfehler						1						1			2
Mitarbeiterfehler															0
Arbeitsanweisung															0
Machine- & Werkzeughavarie	1														1
AV-Fehler		1													1
Transportband/Transport															0
Beschädigung durch Stapler															0
Andere Faktoren															0
															0
															0
Undefinierte Faktoren															0
Total	2	3	1	0	0	2	0	0	0	0	0	1	0	4	**13**

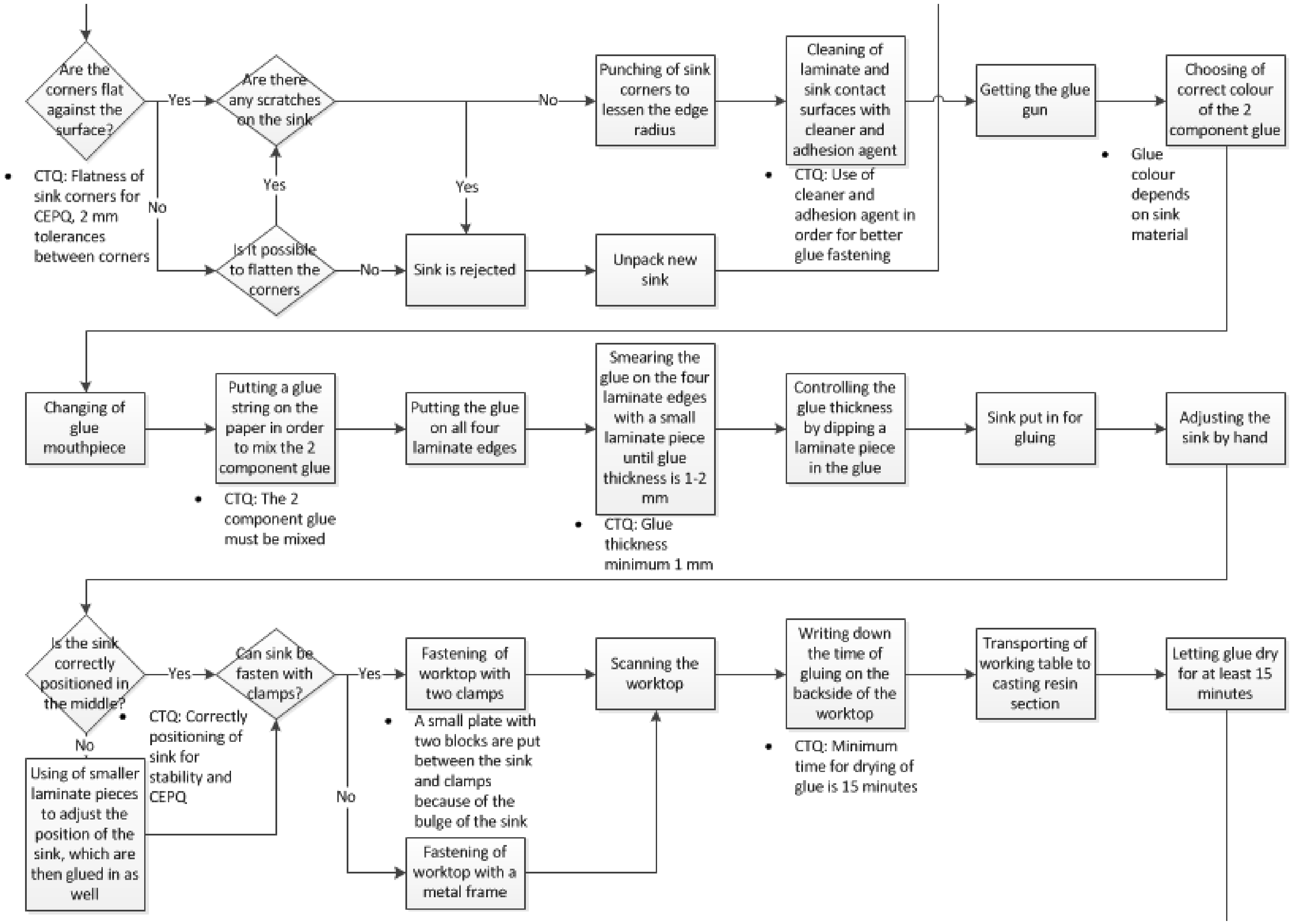
PPM Danform, Laminate worktops

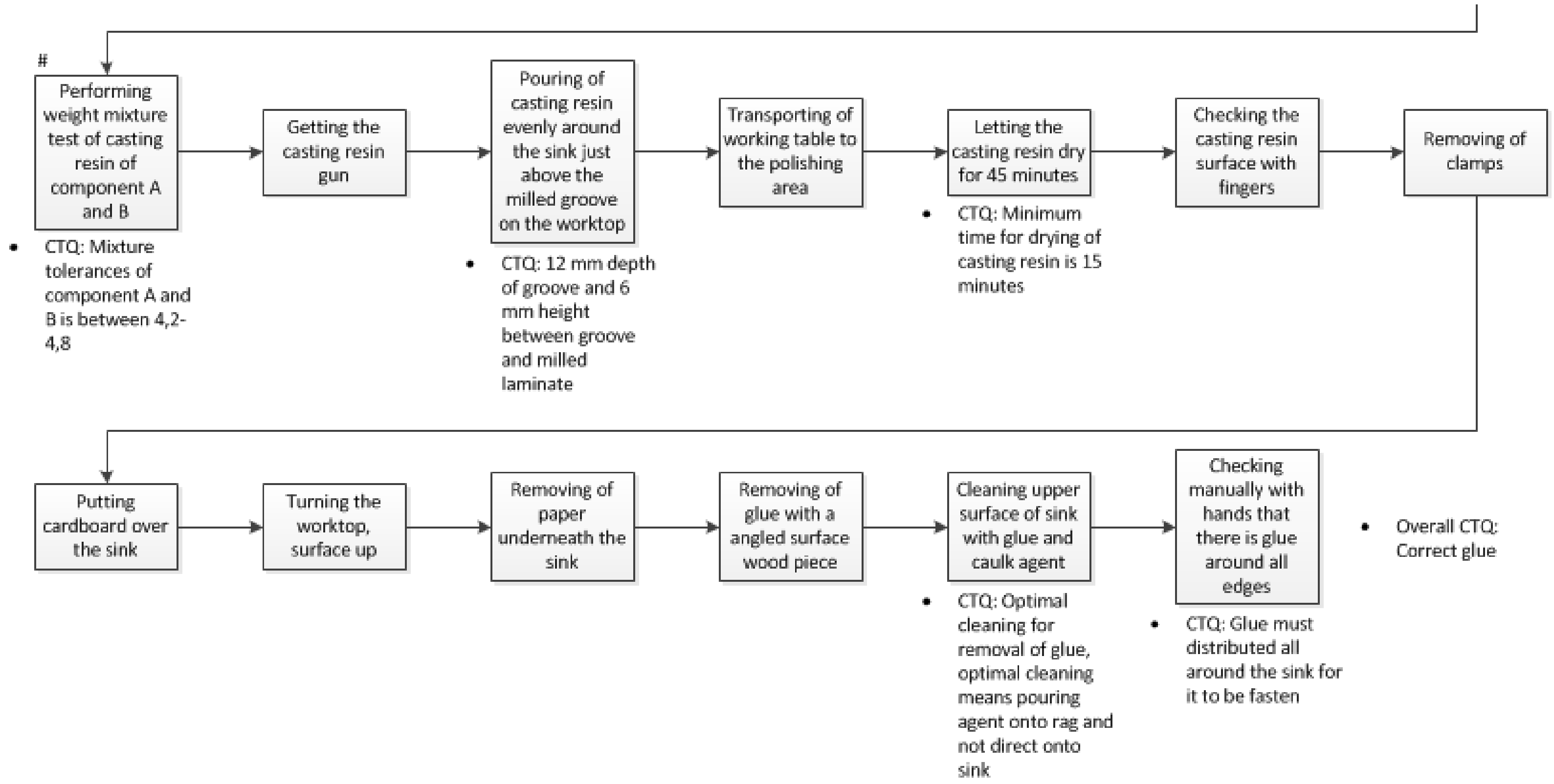
	PPM Laminate																					
	qQ																					
Danform	Maßfehler	Winkelfehler	Stossfehler	Fräsenfehler	Post formed konstruktionsfehler	PP-Kante zu kurz	Alukante Verleimung nicht gut	Dekorfehler	Dekor Falsch	Kante Riss	Kante Ausbruch	Kante Eindruck	Kante Kratzer	Oberfläche Ausbruch	Oberfläche Eindruck	Oberfläche Kratzer	Versiegelung schlecht	Spanplatte schlecht	Delle/Pickel	Spüleneinbaufehler	Übriges	**Total**
Machine & Werkzeug	3	1		1						1				1	1		1				13	22
Programmierungsfehler			1																		2	3
Platte Verschoben			3																		21	24
Materialfehler								20	3	2	9			7	6	4		4	13		8	76
Mitarbeiterfehler				1								3				2					2	8
Arbeitsanweisung																						0
Machine- & Werkzeughavarie												1		1								2
AV-Fehler	4		1																		3	8
Transportband/Transport											3	3		6	11	3					1	27
Beschädigung durch Stapler															1							1
Andere Faktoren									1						1							2
Presse																					1	1
Vacuum test nicht bestanden																				5	2	7
Undefinierte Faktoren	3			1	1			1	1	1	8	4	5	11	6	5		1			3	51
Total	10	1	5	3	1	0	0	21	5	4	20	11	5	26	26	14	1	5	13	5	56	**232**

Appendix 4

Process mapping of procedure of building-in sinks, Lechner




Are the corners flat against the surface?
Yes
No
CTQ: Flatness of sink corners for CEPQ, 2 mm tolerances between corners
Are there any scratches on the sink
Yes
Is it possible to flatten the corners
No
Sink is rejected
Yes
No
Punching of sink corners to lessen the edge radius
Unpack new sink
Cleaning of laminate and sink contact surfaces with cleaner and adhesion agent
CTQ: Use of cleaner and adhesion agent in order for better glue fastening
Getting the glue gun
Choosing of correct colour of the 2 component glue
Glue colour depends on sink material
Changing of glue mouthpiece
Putting a glue string on the paper in order to mix the 2 component glue
CTQ: The 2 component glue must be mixed
Putting the glue on all four laminate edges
Smearing the glue on the four laminate edges with a small laminate piece until glue thickness is 1-2 mm
CTQ: Glue thickness minimum 1 mm
Controlling the glue thickness by dipping a laminate piece in the glue
Sink put in for gluing
Adjusting the sink by hand
Is the sink correctly positioned in the middle?
Yes
No
CTQ: Correctly positioning of sink for stability and CEPQ
Using of smaller laminate pieces to adjust the position of the sink, which are then glued in as well
Can sink be fasten with clamps?
Yes
No
Fastening of worktop with two clamps
A small plate with two blocks are put between the sink and clamps because of the bulge of the sink
Fastening of worktop with a metal frame
Scanning the worktop
Writing down the time of gluing on the backside of the worktop
CTQ: Minimum time for drying of glue is 15 minutes
Transporting of working table to casting resin section
Letting glue dry for at least 15 minutes



Performed once in the beginning of every working day