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Cost of Poor Quality; definition and development of a process-based framework

Master of Science Thesis in the Master Degree Programme Quality and Operations Management

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Gothenburg, Sweden, 2013

Report No. E2013:026

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Acknowledgement

This master thesis has been performed for the master program Quality and Operations Management at Chalmers University of Technology, department Quality Sciences. The case study has been performed at a case company in Gothenburg during the spring semester 2013. We believe that this thesis has been a great opportunity for us which has further enhanced our educational development.

First of all we would like to express our appreciation to everyone involved in our thesis at the case company. Especially, we would like to thank our supervisor for being a great support throughout the whole process and for always taking time to help us and answer our questions. Further, we would like to thank all interviewees for valuable input.

Second, we would like to thank our supervisor at Chalmers, Ida Gremyr, for the great support, input and encouragement throughout the process. Thank you for having triggered our minds for generating the best possible result!

Gothenburg, May 2013

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Abstract

High quality is critical for sustaining competitive advantage. Historically, companies have had the apprehension of that high quality equals high costs, while it in fact is the lack of quality that costs. Therefore, the term *Cost of Poor Quality* (CoPQ) has risen, which can be defined as the total losses caused by the products and processes of a company not being perfect. By measuring and quantifying CoPQ, issues are more likely to be attended by the upper management and fast actions for improvements are more likely to occur. It is often claimed that the cost of poor quality stands for 10-40 percent of the company´s turnover, which is why it is important to measure and monitor CoPQ.

The purpose of this master thesis is to develop a practical framework for continuously measuring and monitoring CoPQ in the production processes of a manufacturing company.

For this master thesis, both qualitative and quantitative research methods have been used. A case study design has been applied in order to obtain in-depth and detailed knowledge. Triangulation was used in order to increase the validity and reliability of the report. Thereafter, the theoretical and empirical findings were analyzed.

It was found that a chain of involved employees followed problems discovered in one department, and it was concluded that costs not known by the company were generated for each problem. Therefore, process-mapping was compiled for different processes in each manufacturing department in order to trace costs within and between each step of the process. It was found that generic models for CoPQ cannot be developed for companies with a low-batch manufacturing strategy containing customized solutions. In cases where process-maps cannot be generalized, the company has to measure specific problems case by case. Subsequently, a practical step-by-step guide for process-based investigation of CoPQ was developed in order to identify CoPQ in the production process. The model can be used in the entire manufacturing process for identifying CoPQ, modifiable overtime as the processes of the company are improved.

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1. Introduction

The introduction gives a background to the chosen subject of investigation, presents the case company as well as the purpose, problem formulation and delimitations.

1.1 Background

"If we can define it – we can measure it;
If we can measure it – we can analyze it;
If we can analyze it – we can control it;
If we can control it – we can improve it" (Dahlgaard et. al., 1998, in Krishnan, 2006, p 99)

In the market situation today with high competition, most companies are challenged to provide their customers with products and services at a low cost without affecting the quality of the product (Bergman & Klefsjö, 2001). Previously, companies have had the apprehension that high quality equals high costs, while it in fact is the lack of quality that costs (Harrington, 1999). Bergman and Klefsjö (2010) therefore stress to use the term *Cost of Poor Quality* (CoPQ), in order to underline that it is poor quality that is costly. Sörqvist (2001, p 30) defines CoPQ as "the costs which would be eliminated if a company's products and the processes in its business were perfect". In current literature on CoPQ, different authors have chosen to establish different frameworks, emphasizing different categories of CoPQ (Tsai, 1998). The reason for this is that companies have various problems and needs and therefore needs to focus on different prioritized areas. Further, the different categorizations are due to different interpretations and focuses (Sörqvist, 2001).

Moreover, companies have had little knowledge regarding CoPQ and as a consequence many companies do not measure those (Krishnan, 2006). Harrington (1999) means that CoPQ has to be measured to be able to control and manage it. Without measuring, information relevant for decision-making will be hidden (Harrington, 1999). It is often claimed that CoPQ stands for 10-40 percent of the company´s turnover and that it is directly linked to profitability (Krishnan, 2006; Sörqvist, 2001; Harrington, 1987). Gryna (1999) highlights the importance of quantifying and transforming CoPQ into monetary terms in order to overcome the gap between the quality department and upper management. By presenting the overall size of the CoPQ and quantifying it into monetary terms, issues are more likely to be attended by the upper management and fast actions are more likely to occur (Krishnan, 2006). Feigenbaum (1991) further states that CoPQ creates the economic common denominator where the management can communicate clearly and effectively with each other and where investments in quality improvements can be evaluated in relation to other improvements and profit enhancement.

1.2 The case company

The case company is a Swedish high technological company operating in five business areas. The company had an annual sales of SEK 23,5 billion in 2011, where 63 % of the total sales is outside Sweden, and the most important customer base is situated in Europe, South Africa, Australia and USA.

The business area in focus of the report is situated in Gothenburg, with supporting plants in Sweden and abroad.. In 2011, the business area represented SEK 4,6 billion of the annual sales. The products include high technological systems used in airborne, land based and naval systems. Approximately 3000 systems had been sold in 30 different countries.

The organizational structure is built on a matrix organization, including a line and project organization. The purpose of the line organization is to supports the business where competences, products and processes need to be built and maintained, meanwhile the purpose of the project organization is to create flexibility and ability to meet the variations in demands of the customers. The business area is further divided into four main functions; sales, project, R&D and supply. Those are in turn managed by supporting functions.

1.3 Purpose

The purpose of this master thesis is to develop a practical framework for continuously measuring and monitoring CoPQ in the production processes of a manufacturing company.

The purpose will be fulfilled by doing a case study, with the basis of identifying and analyzing CoPQ arising in the production processes.

1.4 Problem formulation and research questions

Today, the case company has limited knowledge of their CoPQ, consequently the apprehension of the extent is unknown. The identification of where CoPQ arises is important for further analyses and improvements (Dahlgaard et. al., 1998). Therefore, in order to find areas of improvements, an identification of CoPQ in the case company needs to be done, where the company needs to understand the processes of their organization in order to be able to identify and measure CoPQ (Harrington, 1987). Further, Sörqvist (2001) emphasizes that it is difficult to identify which cost items to include as CoPQ, due to lack of distinction between CoPQ and other costs items. Both Dale & Plunkett (1991) and Sörqvist (2001) highlight the “grey zone” in between, in which no clear differentiation of cost items are defined. Different authors have tried to classify CoPQ into categories, but with different views on which categories to include in the framework. It has been said that there is no single generic classification used by all companies, instead companies customized their on framework (Sörqvist, 2001). A reason for the customization is that cost items differ between companies due to the complexity of the products, how the technology provided by the company is used and how customers use the product (Harrington, 1987). In order to accomplish the purpose it was necessary to break down the purpose of this report into two of research questions, where the first is addressed below;

How can CoPQ be categorized in a manufacturing company?

Both Sörqvist (2001) and Dale and Plunkett (1991) agree that CoPQ items are hard to identify and differs between companies. However, it is stated by the same authors that that CoPQ have to be measured in order to be monitored and controlled. Harrington (1987) further stress that the use of CoPQ gives the company a tool for measuring the consequences of poor quality, and the impact of the improvement work. Since CoPQ differs between companies, but is still crucial for working with CoPQ, a second research question has been developed;

How can CoPQ be identified?

1.5 Delimitations

This master thesis delimits to only focus on the operational plant in Gothenburg. Therefore, none of the other plants of the case company will be studied.

The scope of the master thesis is to investigate the cable-manufacturing department and system-installation department. Further, the scope is defined from delivery of a component from a supplying department until the component is passed further to the next department in the production chain. The supporting functions in terms of HR and finance will not be included.

Further, the scope of the master thesis is to construct and test the given model from the analysis. The thesis can therefore be seen as pilot study for further projects at the company. Consequently, the master thesis delimits from suggesting implementation plans.

2. Methodology

The methodology chapter starts by describing the chosen research strategy and design, explains how the research was performed, further describes the theoretical study and the empirical study and finally discusses the quality of the research.

2.1 Research strategy and design

Defined by Bryman and Bell (2011, p 26) the *research strategy* is "a general orientation to the conduct of business research", and is divided into *qualitative* and *quantitative* research. Quantitative research means transferring information into numbers and amounts and then conduct statistical analysis (Creswell, 2009), while for qualitative methods words and the researcher's interpretation and perception of them is in focus (Andersen, 2000).

Further, the *research design* should give a structure for how the data collection and its analysis are performed (Ghauri & Grønhaug, 2010). According to Bryman and Bell (2011) the research design can be divided into; *experimental, cross-sectional, longitudinal, case study, comparative* and *levels of analysis*. For this master thesis a case study design has been chosen which Bryman and Bell (2011, p 60) define as "a single object of interest in its own right, and the researcher aims to provide an in-depth elucidation of it". When a case study is performed, detailed and in-depth information can be gained as well as a customized problem formulation for the company (Yin, 2003). Dubios and Gadde (2002, p 555) further discuss the benefits of a case study as "case studies provides unique means of developing theory by utilization in-depth insights of empirical phenomena and their contexts".

A case study can be qualitative as well as quantitative, or be based on a mix of the two (Yin, 2003). According to Holme and Solvang (1996) the problem formulation decides if one of the two methods is preferable or if either or can be used for the same situation. This is mentioned by Bryman and Bell (2011) as *mixed methods* research, which is used to minimize the limitations of one research strategy (Creswell, 2009). Due to the problem formulation of the master thesis it has been necessary to use both qualitative and quantitative information since the purpose is to identify where the largest CoPQ arises and to measure them. In order to identify and measure these costs, data from the error-handling system has been used to find the most common problems while interviews and observations have been used to find problems not reported in the system.

Moreover, Bryman and Bell (2011) explain the relationship between theory and research as being either *deductive* or *inductive*. The deductive approach is when research use theory to frame the observations and findings while inductive approach is when the theory is the outcome of the research (Ghauri & Grønhaug, 2010). However, deductive approach entails an element of induction while inductive approach entails an element of deduction (Bryman & Bell, 2011). Furthermore, Kirkeby (1994) states that a problem with the both approaches are that it cannot provide the knowledge of something that is new or the knowledge of something which is not already known. Therefore, the *abductive* approach is introduced and is according to Haig (2005, p 377) "a form of reasoning involved in both the generation and evaluation of explanatory hypothesis and theories". The approach is associated with creation of new concepts and development of theoretical models with no confirmation of existing theory (Magnani, 2001). Kirkeby (1994) summarizes the three approaches by stating that abduction is where the hypothesis arises, deduction is when facts have been derived from the hypothesis, and induction tests the validity of the received empirical facts.

Systematic combining, proposed by Dubois and Gadde (2002), which is a method used for case studies, is inspired by the abductive approach. The method is a process where theoretical framework, empirical fieldwork and case analysis develop concurrently, see figure 2.1. In practice, this means to go "back and forth" between the empirical study and the theoretical study in order to expand the comprehension of the two phases. Further, initially the data analysis consists of preconceptions which later evolve through the empirical study, analysis and interpretation.

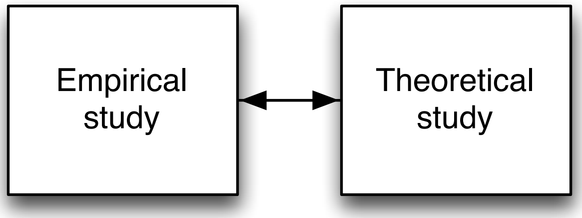

Figure 2.1 - Systematic combining (Dubois & Gadde, 2002)

Systematic combining has been used throughout the master thesis, which means that the empirical and theoretical study has been matched continuously during the research process by letting the empirical study affect the choice of theory. This has supported the empirical study and allowed for adequate conclusions to be drawn. The purpose to use systematic combining was to adopt and enhance the existing theory by matching it for the case company, and not only to generate a new general theory. Moreover, the research process is not a linear process where each activity is completed and finished. Instead it is an ongoing process where the activities go back and forth simultaneously, which is necessary in order to understand the problems and the theory.

2.2 Research process

The research process, see figure 2.2, started by defining the problem; to develop a framework for continuously measuring and monitoring CoPQ at the case company. A process started to limit the master thesis to a manageable area, which ended up with delimitation to the cable-manufacturing department and the system-installation department. The choice of these two departments was based on recommendations of the supervisor at the case company and gathered information from key employees from both the manufacturing department and the quality department. From the information gathered it was concluded that those two departments were suffering from a high amount of quality problems. The choice was further due to the wide range of products processed in those two departments; thus was considered appropriate to find most of the deficiencies.

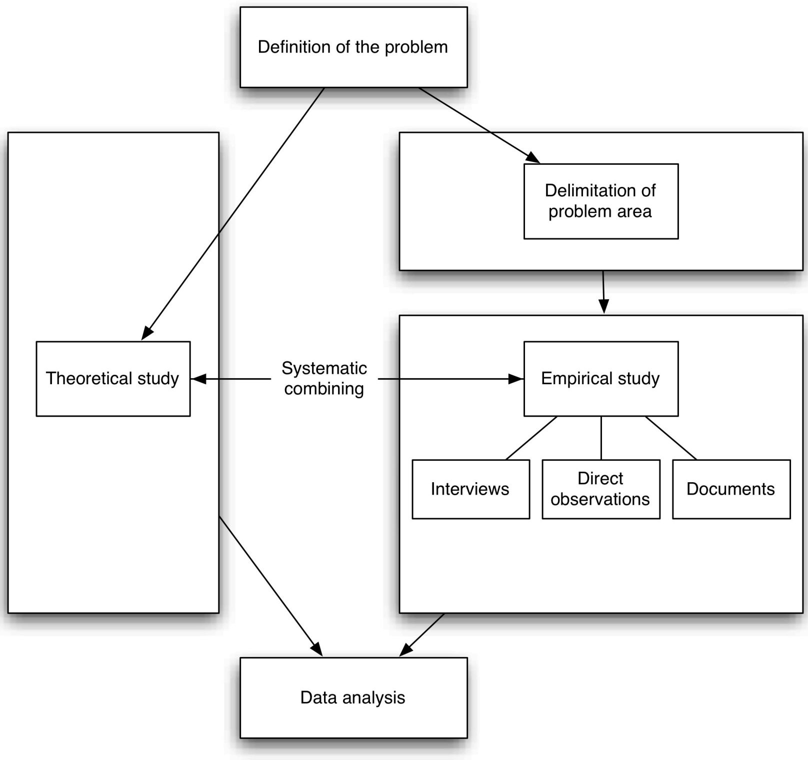

Figure 2.2 – The performed research process

Simultaneously with the delimitation, the theoretical study started by looking for relevant books and articles. When basic knowledge had been acquired, the empirical study started in parallel with the theoretical study. The theoretical study was finalized with a summarized theoretical framework, based on the different inputs from the literature study. Moreover, the empirical study was divided into three parts; *interviews, direct observations* and *documents*, which were carried out concurrently.

In the analysis the problems identified were clustered into common denominators and the processes caused by the problems were mapped and generalized to make the proposed framework useable throughout the production process at the case company and for similar companies. Thereafter, the CoPQ-framework was developed which was based on the empirical and theoretical findings. Further, the CoPQ was quantified in order to understand the consequences of lack of quality and some practical steps for measuring CoPQ were developed. Finally, the framework was tested and CoPQ was measured.

2.3 Literature study

As stated by Bryman and Bell (2011), the purpose with the literature study is to obtain knowledge about what is already known about the chosen topic. Furthermore, the literature study provides a base to validate the research questions and how to collect and analyze the information.

The literature used has been books and scientific articles. Those were chosen from the recommendations of the supervisors at both Chalmers and the case company, own searches at Chalmers Library or Google Scholar and own experience from literature in previous courses at Chalmers. To find the relevant literature keywords such as *cost of poor quality*, *quality costs, poor quality costs*, *lean manufacturing* and *quality management* have been used.

According to Gillham (2010), it is important to first get an overview of the research topic in order to get an understanding and later go deeper into the specific area of interest. Andersen (1994) continues by emphasizing that the knowledge about the topic should first be broad whereupon a deeper analysis about the topic can be made. Thus, first general and unclasps sources should be reviewed and subsequently more specific sources be used.

The master thesis started with a broad search to acquire a wide basis of knowledge in quality management and then deepened into CoPQ. However, when deeper knowledge had been acquired in CoPQ a need to include Lean Manufacturing together with theory regarding CoPQ was considered necessary and consequently it had to be added in the theoretical study.

Throughout the literature process *snowball sampling* has been used, this means letting one book or article lead to other literature and consequently the framework grows like a snowball (Bryman & Bell, 2011).

2.4 Empirical study

In the collection of the empirical data *triangulation* has been used which means using multiple sources of evidence collecting the information (Yin, 2003). Thurmond (2001) emphasizes that triangulation can be used to decrease, negate or to compensate for deficiencies a single strategy provides and thus increase the ability to interpret the data in a better way. The triangulation is according to Dubois and Gadde (2002) connected to systematic combining by using multiple sources of evidence, but with the difference of systematic combining emphasizes on revealing aspects unknown for the researcher while triangulation is about checking the accuracy of data.

Yin (2003), Gillham (2010) and Remenyi et. al. (1998) state six important sources to collect the empirical data when conducting a case study; *documents, interviews, direct observations, participant-observations, physical artifacts* and *archival records* (Yin, 2003; Gillham, 2010; Remenyi et. al., 1998). Further, none of these six sources has a complete benefit over all the others but rather are supplementary where it is better to use as many sources as possible (Yin, 2003). In this master thesis interviews, direct observations and documents have been used as sources of evidence. This was due to previous experience in the three chosen sources of evidence and lack of knowledge in the other three; participant-observations, physical artifacts and archival records. Further, it was also because of the limited time for this master thesis and that it is time-consuming to use all six sources of evidence.

2.4.1 Interviews

Interviews are according to Remenyi et. al. (1998) and Yin (2003) one of the most commonly use methods to collect data in a case study. Furthermore, Bryman and Bell (2011) state that *semi-structured* and *unstructured* interviews are the major types of qualitative interviews with the benefit to be flexible and where the interview can change its focus to the most important in each specific situation (Bryman & Bell, 2011). Moreover, the collection of empirical data through interviews is central for qualitative studies where both personal and situation-dependent factors have great influence (Wallén, 1996).

The interviews were performed with employees that the authors of this master thesis together with the supervisor at the case company considered to possess knowledge and experience in the area of CoPQ. Moreover, additional interviews with employees outside the chosen departments was needed and had the purpose to provide insights to the problems in the manufacturing department from an external viewpoint, based on recommendations from earlier interviews.

The first three interviews with the production manager and quality engineers in the manufacturing were unstructured. Unstructured interviews are when the interviewee is allowed to answer and elaborate freely on the topic and where the interviewer responds to interesting points (Bryman & Bell, 2011). This interview method can be used to find out the areas of interest (Bell, 2006). The purpose with the interviews was to get a broad picture of the production processes, in order to find where the main problems arise and to delimit the research area.

For the remaining interviews, semi-structured interviews were used. 20 interviews within the chosen departments were held with department managers, production engineers, production planners, inspectors and operators. Further, ten interviews with employees external to the departments were held, with employees from R&D, material planning, incoming inspection and storage, purchasing, system-test and engineering workshop, see the list of interviews in appendix I. Semi-structured interviews are according to Gillham (2010) the most important interview form in a case study research and can, if it is conducted in a good way, be the best single source of information. Further, semi-structured means that topic and questions are pre-planned but there is flexibility regarding the sequence of questions and the interviewee can explain and advance its ideas (Björklund & Paulsson, 2007).

Since the interviews have been conducted with different employments, from different departments and of different types, unstructured or semi-structured, several interview guides have been used. However, equal guides have been used for the same position within the company in order to address the same areas of interest and similar questions have been reused in the different guides. For the interview guides, see appendix II.

The goal with the semi-structured interviews were that the questions should not be slanted or formulated in a way that makes the person answers in a certain way or feels exposed (Olson, 2007). Therefore, the interviews started with open questions and during the interview the questions were more specific. Both authors of the master thesis performed the interviews, both asking questions and taking notes in order to ensure that a clear understanding of the topic was obtained and to secure that no information was missed.

Each interview was performed face-to-face and took approximately ten minutes for the operators while between a half-hour up to two hours for the rest of the interviews, performed in their native language Swedish. Further, during the interviews the interviewee was informed that their answers would be kept anonymous. When follow-up questions arose after the interviews, which did not arise during the interviewing, these were emailed to relevant employees in order to save time for both the authors of this master thesis and the employees.

During the analysis, four follow-up interviews with department manager, production engineer and production planner were conducted to ensure that has been found correlates to what has been said in the empirical study. The interviews were also semi-structured but shorter, between a half-hour and an hour.

2.4.2 Direct observations

Observations were performed in order to get an understanding of the material and information flow, how the work is conducted by the operators and which problems that can occur in different stages of the process (Magnusson et. al., 2003). According to Yin (2003) direct observation can be used in order to get additional information about the studied subject. Remenyi et. al. (1998) states that direct observations give strength to what is said in interviews and written in documents. Through observations the surroundings can directly be observed together with relevant interaction and behavioral and environmental conditions.

Direct observations were used to grasp how the products look like, how they are manufactured, how the production process look like, to see and hear the interactions between the operators and to identify CoPQ. Further, the direct observations were performed in order to analyze if the information from the interviews and documents links with what has been observed. The cable-manufacturing department and the system-installation department have been observed as well as an external department; incoming inspection and storage. In total five observations were performed which took approximately a half-hour up to two hours, see the list of observations in appendix III.

2.4.3 Documents

As explained by Bryman and Bell (2011), there are many ways to document data; through *personal documents, public documents, organizational documents, mass media outputs, visual documents* or *virtual documents*. According to Yin (2003), documents are often used to verify and strengthen information from other sources. However, it is important to consider the purpose of the documents since they have been written for a reason other than research and therefore there is a risk to reflect a specific situation (Remenyi et. al., 1998).

In this master thesis, to get a comprehension of relevant processes, organizational documents from the intranet of the case company have been used and analyzed. Further, documents from the error-handling system of the case company has been used to map up the most commonly reported problems from the two departments and to obtain an understanding of their frequency and causes. The data from the error-handling system has been used to verify the findings from the interviews and observations.

2.5 Data analysis

A main challenge when analyzing qualitative and quantitative data is the large amount of data collected from interviews, documents and observations (Bryman & Bell, 2011). Consequently, the *data analysis model* described by Miles and Huberman (1994) will be followed in this thesis. Miles and Huberman (1994) divide the model into three parts; *data reduction*, *data display* and *conclusion drawing and verification*.

Data reduction means the process of selecting, focusing, simplifying, abstracting and transforming the information to make it manageable and meaningful, which means to categories and identify similarities and patterns. Moreover, the data display is performed by organizing and presenting information in a clear way, to make valid conclusions (Miles & Huberman, 1994).

From the interviews, observations and documents a large amount of problems were found, where the most common problems were analyzed to find their causes and effects. The problems were clustered into common categories and denominators, and thoroughly investigated to find the reason for the problems. Simultaneously, the effects of the problems were examined to find the cost items each problem resulted in.

The findings from the empirical study together with the theoretical study led to a refined framework. To make the refined framework useful throughout the production process and not only for the cable-manufacturing department and the system-installation department, it had to be generalized. The generalization of the framework is in line with the purpose; to come up with a framework to measure CoPQ in the entire production process. Subsequently, the problems were mapped in order to find the process each problem caused. Further, for a company to know how to identify, choose and measure CoPQ a process was developed consisted of practical steps to follow.

In order to measure the problems, the cost items had to be quantified. Consequently, when possible a value was assigned to a cost item and when not, average standard cost was used. To find those average standard costs, estimates from the employees were used.

2.6 Research quality

Both Remenyi et. al. (1998) and Yin (2003) state four criteria to evaluate the research quality of a case study. These criteria involve; *construct validity*, *internal validity*, *external validity* and *reliability*.

Validity is the ability of the research to give answers on the research questions, and how they are answered and reviewed. The connections must relate in a correct way and consequently the case study processes what it aims for (Eriksson & Wiedersheim-Paul, 2006). Construct validity is by Remenyi et. al. (1998, p 179) defined as "establishing correct operational measures for the concepts, ideas and relationships being studied". Thus, identify the studied ideas, concepts, relationships and issues to see if they relates to the selected measurements in the research (Remenyi et. al., 1998). The construct validity has been strengthened by using triangulation, which is stated by Yin (2003) and Remenyi (1998) to be a good way to avoid poor validity.

Moreover, internal validity means compliance between the observations of the researcher and the theoretical ideas that have been developed (Bryman & Bell, 2011). To avoid the problems with internal validation, all information has been critically viewed and through triangulation, different point of views has been given and verified the empirical findings of the master thesis. Further, through interviews with several employees within the same position and from external departments the internal validity has been avoided.

External validity, for a case study, can be generalized beyond the immediate research (Bryman & Bell, 2011). The generalization is described by Yin (2003) as a major problem for case studies, and therefore it has been important to minimize this as much as possible. The aim of the master thesis was to develop a measurement method manageable in any manufacturing company and consequently large efforts have been made to increase the generalization. However, it was not possible to minimize the problem completely and therefore some aspects of the measurement method are specific for the case company.

Furthermore, reliability can be defined as the consistency of a measure of a concept (Ejvegård, 2012). While Yin (2003) and Remenyi et. al. (1998) only states reliability, Bryman and Bell (2011) split reliability into external and internal. *External reliability* means the degree to which the research can be replicated while *internal reliability* is when there is more than one observer that agree upon what is seen (Bryman & Bell, 2011). The replication of a case study is troublesome and it is not likely that the same findings are usable since the environment and conditions are continuously changing in the company. Therefore the external reliability can be minimally affected. Further, the internal reliability have been strengthened throughout the data collection by always be the two authors of this master thesis during the interviews, observations and investigation of the documents.

Additionally, the bias in a qualitative study can be a problem (Remenyi et. al., 1998). This means that the research only relies on the views and interpretations of the authors, and not the objectivity from the surroundings (Bryman & Bell, 2011). The use of triangulation has together with the different opinions of the authors of this master thesis been seen as a way to decrease bias, and has as a result increased the impartiality together with the validity and reliability.

3. Theoretical framework

The theoretical framework is divided into following sections; Lean Manufacturing, Introduction to quality, Introduction to Cost of Poor Quality and Use of CoPQ measurements.

3.1 Lean Manufacturing

With the situation in the market today with high competition, meeting customer demands of providing exactly what the customer wants and when they want it challenges most companies. Further, the product should obtain a high quality and a reasonable price (Bergman & Klefsjö, 2010). Customer demands are essential to be met in order to keep a competitive advantage. For this reason, more flexible and fast processes are required in order to decrease delivery time and increase quality (Slack & Lewis, 2011). During the 1950s, the Japanese car manufacturer Toyota started to focus on flexible and fast production systems, which has become the foundation for the philosophy of what we today call *Lean Manufacturing* (Liker, 2009). The focus of Lean Manufacturing is to eliminate non-value added activities and create a consistent flow by working with continuous improvements (Slack et. al., 2010).

3.1.1 The foundations of Lean Manufacturing

The foundations of Lean Manufacturing can be symbolized as a building, held up by the two pillars; *Built-in Quality* (*Jidoka)* and *Just-in-time (JIT)*, see figure 3.1 (Nicholas, 2010). The roof represents the goals of the organization of having highest quality, lowest costs and shortest lead-time, whilst the foundation is represented by standardization and the importance of having stable and reliable processes (Liker, 2009).

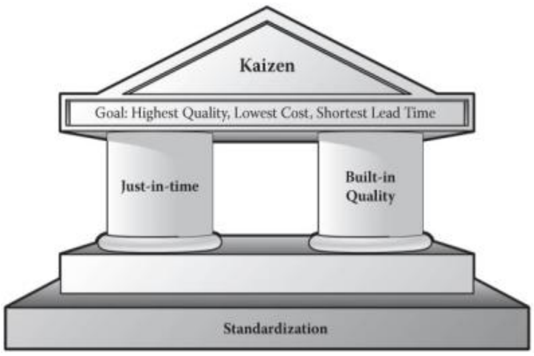

Figure 3.1 - The Lean house (Nicholas, 2010)

The goals of the organization are achieved by having *kaizen*, which is the Japanese word for continuous. The concept of kaizen regards having continuous improvements in the organization, meaning that it is always possible to improve products, processes and methods, while using less recourses (Bergman & Klefsjö, 2010). Stewart (2012) means that standardization is the foundation for the complete production system. Without standardization in an organization, it is like building a house upon the sand; each day, the sand shift and can destroy any improvements that have been made. Consequently, the foundation of the house must be strong and immovable.

Jidoka is a concept of working with the interface between man and machine. The concept origins from never letting a defect pass to the next station by freeing people from machines, meaning automation with human intelligence. Thus, quality is built into the whole production process (Stewart, 2012). If a quality problem occurs the problem should be adjusted immediately (Nicholas, 2010). Liker (2009) means that it is more effective and less costly to prevent problems from occurring than to repairing quality problems afterwards. Moreover, Just-in-time is a concept that refers to getting the exact right thing to the exact right place at the exact right time in the exact right quality and quantity order to achieve the perfect work flow (Slack et. al., 2010).

3.1.2 Types of wastes

Liker (2009) means that activities in a process can be *value adding* or *non-value adding.* Value-adding activities can be defined as activities that add value to a product, from the perspective of the customer hence the customer is willing to pay for it (Liker, 2009). Non-value adding activities can be described as waste, which can further be placed in one of the seven categories; transport, inventory, unnecessary motion, waiting time, over-producing, over-processing and defects, as described in table 3.1 (Nicholas, 2010).

Table 3.1 The seven categories of waste (Nicholas, 2010)

The seven categories of waste	**Explanation**
Transport	Moving work in process (WIP) or components between processes or warehouses
Inventory	Components, WIP, finished product not being processed
Unnecessary motion	People or equipment moving or walking more than required
Waiting time	Waiting for the next step in the production
Over-producing	Production ahead of demand
Over-processing	Inefficient processing due to poor tools or poor product design
Defects	Inspecting for and fixing defects

Liker (2009) further means that there are activities that do not add any value to the product, but still are essential for the process and the daily work. Those activities are referred to as *necessarily non-value adding activities,* which are activities that should be identified and reduced, but cannot be completely eliminated. This can be activities which make employees more comfortable and in turn increase efficiency of the employees, but does not directly add value to the product. It can also be steps that are crucial for the production process, but do not add value to the product per se.

3.2 Introduction to quality

Quality is a concept with many different meanings and definitions (Juran & De Feo, 2010). Previously, managers have had the apprehension of that high quality for products and services only equals to a higher unit cost. But this changed in the 1970s and 1980s when companies found that high quality resulted in greater return on investments and increased market share for the company (Harrington, 1999). The former focus on quality of the products has today shifted towards focus on additional services of all the business areas in the company (Sörqvist, 2001).

3.2.1 Quality management

Three of the pioneers discussing quality management were Edward W. Deming, Joseph M. Juran and Philip B. Crosby, all proposing different approaches regarding quality management. Deming (2000), stress that quality management involves the systematic nature of organizations, the importance of leadership and the need of reducing variation in processes. The context emphasized by Juran and De Feo (2010) regards three sets of activities; quality planning, control and improvement, emphasizing that in order to eliminate deviations, statistical tools should be used. Crosby (1988), on the other hand, focuses on reducing costs through quality improvements, meaning that both high-end and low-end products can maintain good quality.

Dean and Bowen (1994) mean that quality management can be seen as a philosophy or approach to management, characterized by different principles, practices and techniques. The principles are described by customer focus, continuous improvement and teamwork, implemented by a number of practices such as collecting customer information and analyzing processes. The principles are in turn supported by different techniques, such as customer surveys, pareto analysis, statistical process control and team-building methods.

3.2.2 Definition of quality

A common definition of quality is according to Juran and De Feo (2010, p 5) "fitness for use" which has subsequently been developed to "fitness for purpose" This means that in order for a product to fit for its purpose, every goods and service must have the right features to satisfy customer needs, and further must be delivered with few failures (Juran & De Feo, 2010). Crosby (1988, p 78) explains quality as "conformance to requirements", stating that the definition of quality from the management must be clear. Another definition is described by Deming (2000, p 5), stating that "quality should be aimed at needs of the customer, present and future". Sörqvist (2001) means that all definitions regarding quality have customer orientation as the common denominator, where the quality from the supplier should be seen from the perspective of the customer.

According to Evans (2000), customer-driven quality is fundamental to high-performing organizations. Deming (2000) states that maintaining a higher quality leads to a long-term competitive strength. This is due to that improved quality lead to decreased costs because of less re-work, fewer mistakes, fewer delays and better use of time and material. This in turn improves productivity, which captures the market with better quality and lower price, and consequently the company will stay in business and provide more jobs. Sörqvist (2001) also stress that high quality results in increased productivity, lower costs, and often a higher demand on the products and services the companies provide.

Juran and De Feo (2010) view the concept of quality from two perspectives; the mission of the company as a whole to achieve high product quality and the mission of each individual department to achieve high production quality. Therefore, it is important to raise awareness among employees in the company regarding quality (Krishnan, 2006). Employees from different departments of the organization speak in different languages, therefore different communication approaches should be used; financial terms for the management, bilingual language of finance and things for the lower management and the language of things for the workforce. Due to the different languages and different ways of interpreting information, quality needs to be communicated and explained in different ways (Juran & De Feo, 2010).

3.2.3 Internal and external customer

Juran and De Feo (2010) state that there are many different types of customers, some of them are obvious and some less obvious. Sörqvist (2001) defines those as internal and external customers which both need to be satisfied. Bergman and Klefsjö (2010) emphasize that quality has to be valued from the customer and put in relation to their needs and expectation. Customer focus implies finding out their needs, and further systematically trying to fulfill those needs when developing and manufacturing the product (Bergman & Klefsjö, 2010). Customer focus is fundamental in quality management, which makes it essential for companies to handle assessment of customer expectations, customer relationship management and commitment to customers (Dean & Bowen, 1994). Lengnick-Hall (1996) states that there is an relationship between perceived quality and experienced customer satisfaction, which over time shapes what customers expect. Further, if the customer is able to clearly communicate the requirements and usage of the delivered product, the need for re-design and re-work will be reduced.

Marshall et. al. (1998) defines internal customer service as a two-way exchange process between employees of different functional departments, where the provider is charged with responding and satisfying their internal customer (Marshall et. al., 1998). Employees inside an organization play three roles; supplier, processor and customer, where each employee receives something, process it and pass it further to someone else. Many of those relationships are informal and hard to identify (Juran & De Feo, 2010). As a result, organizations try to set up systems, such as meetings, that allow competing functions to resolve differences based on the goal of satisfying the customers. Those systems do not often work, because of the lack of understanding through the need of the internal customers. In turn, this often results in that communication between functions only deteriorates, which is a reason for having cross-functional teams (Marshall et. al., 1998).

Marshall et. al. (1998) further mean that organizational units should provide internal customer satisfaction for the same reasons as they provide external customer satisfaction; increased efficiency, lower waste and lower costs (Marshall et. al, 1998). Both Juran and De Feo (2010) and Marshall et. al. (1998) agrees that meeting the needs of the internal customers have a major impact in serving the external customers.

3.2.4 Quality and profitability

According to Sörqvist (2001) there is a correlation between quality and profitability where high quality results in better profitability. By increasing the product quality in a company, the revenue can increase due to that a higher price can be charged for the products (Sörqvist, 2001). Further, the costs will decrease through reduction of waste in the production, the re-work and scrap is reduced since the products are flawless directly (Ehresman, 1997). Or, as stated by Deming (2000), the product is produced correctly the first time. Moreover, the capital tied up in assets decrease not only because of less need of buffers between work centers and spare parts, but also through higher utilization of facilities due to less re-work and decreased need of control (Sörqvist, 2001). Bergman and Klefsjö (2010) also emphasizes that decreased capital tied up in assets result in increased profitability, but further sees two other positive outcomes; larger profit margins for the company and increased market shares and thereby the profitability in a long-term perspective (Sumanth & Arora, 1992).

Feigenbaum (1991) adds the positive cash flow as a consequence of improved quality for the company, while Harrington (1987) discusses the relationship between quality and profitability, emphasizing that in order to increase a profit of a company it is better to improve the quality than increasing the sales. The reason is that increased sales require more resources such as more equipment, more materials, more floor space and more support employees, which detracts from the earned money. Instead, savings through quality improvements are often directly connected with increased profit creating possibility to continue investing in improved quality and better products (Harrington, 1987). Further, Merino (1988) states that improved quality results in better communication in the organization together with improved communication with its customer.

3.3 Introduction to Cost of Poor Quality

Juran was in year 1951 the first to discuss costs associated with poor quality and how it affects the company, while Feigenbaum five years later was the first to classify these costs into categories (Tsai, 1998). Over the years, many different expressions have been used such as poor-quality cost and quality costs, but as explained by Bergman and Klefsjö (2010) these are not good terms giving the impression that high quality costs, while it in fact is lack of poor quality that costs. Bergman and Klefsjö (2010) therefore advice to use the term Cost of Poor Quality (CoPQ) that will be used throughout this master thesis as a generic name for all costs associated with poor quality. Sörqvist (2001, p 31) defines CoPQ as "the total losses caused by the products and processes of a company not being perfect". Harrington (1987, p 5) on the other hand defines CoPQ as "all the cost incurred to help the employee do the job right every time and cost of determining if the output is acceptable, plus any cost incurred by the company and the customer because the output did not meet specifications and/or customer expectations".

3.3.1 Visible and invisible Cost of Poor Quality

CoPQ can be more or less difficult to identify (Krishnan, 2006), therefore Feigenbaum (1991), Gryna (1999), Dale and Plunkett (1991) and Giakatis et. al. (2001) separate the CoPQ into visible and invisible costs regardless of classifications, stating that visible CoPQ are easy to identify and measure while invisible CoPQ is difficult to identify and measure. Stated by Krishnan (2006) visible and invisible CoPQ can be visualized as an iceberg, where only a little amount of the costs can be seen and the rest is hidden under the water, see figure 3.2. Most often, only visible CoPQ are taken into consideration when talking about poor quality, thus omit the other costs (Krishnan, 2006). However, when the data for invisible costs are credible or manageable, and where estimations can be done, those costs should be included as visible costs (Gryna, 1999).

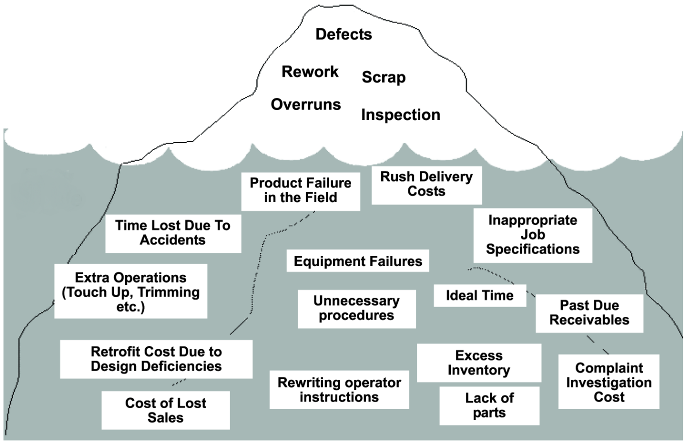

Figure 3.2 – The iceberg of visible and invisible costs (Krishnan, 2006)

Furthermore, Gryna (1999) has divided invisible CoPQ into ten categories while Sörqvist (2001) has a different approach regarding visible and invisible costs, and divide those into five categories depending on their ability to be measured, see appendix IV. The different categories are presented in decreasing visualization which can be compared to the iceberg described by Krishnan (2006); *traditional CoPQ, hidden CoPQ, lost income, customer's costs* and *socio-economic costs*. Traditional CoPQ is visible costs according to Krishnan (2006), while the four remaining costs are invisible. In practice it is only possible to determine parts of traditional CoPQ and hidden CoPQ (Sörqvist 2001).

A major part of invisible CoPQ is unrecognized in companies due to that they are neither measured, nor reported (Krishnan, 2006). Further, invisible costs are unrecognized due to that the costs are inadequately registered in the organization or not discovered at all (Dahlgaard et. al., 1992). As a consequence, management decisions are often based on the information of visible costs (Krishnan, 2006). The authors differently describe the amount of invisible CoPQ, where Gryna (1999) states that invisible CoPQ is three or four times of visible costs while Krishnan (2006) states that invisible CoPQ can be as high as three to ten times visible costs.

3.3.2 Classification of Cost of Poor Quality

In order to clarify what CoPQ means and to further apply this into a particular company, the individual cost items, which reflect the CoPQ, have to be identified (Sörqvist, 1997). Explained by Campanella (1990), the classification of CoPQ is first divided into categories and the categories are then divided in cost items, see figure 3.3. The classification includes different categories and cost items between authors, which will be visualized further down, and can be seen in appendix V.

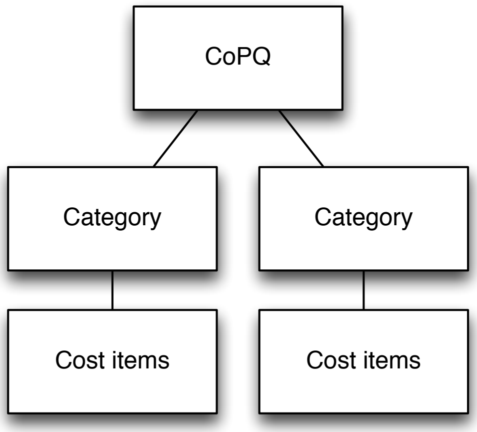

Figure 3.3 – The classification of CoPQ (Campanella, 1990)

As described, Feigenbaum was the first to classify CoPQ into categories. Feigenbaum, (1991) evoked the Prevention, Appraisal and Failure-model (PAF-model) that divides CoPQ into three main categories; *prevention costs*, *appraisal costs* and *failure costs* (Feigenbaum, 1991), see figure 3.4.

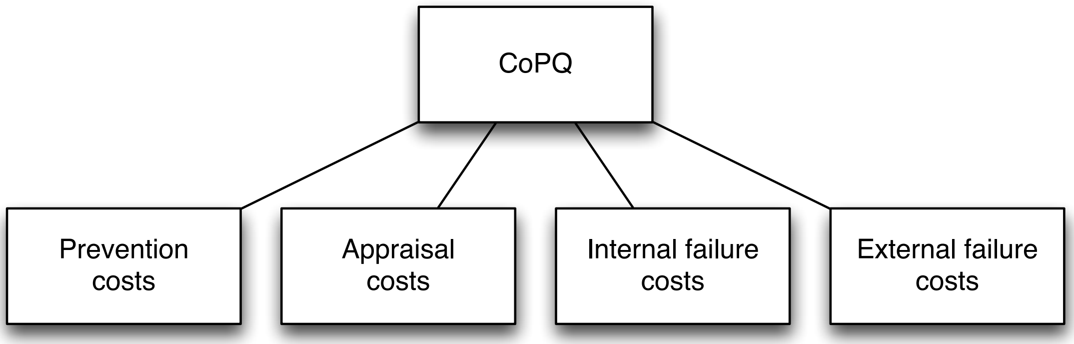

Figure 3.4 - The classification of CoPQ according to Feigenbaum (1991)

The prevention costs are described by Oakland (2003, p 107) as costs "associated with the design, implementation and maintenance of the quality management system". It is all the activities to avoid poor quality from occurring in the first place in products and services (Campanella, 1990) and can be seen to be proactive costs related to building quality into the product (Gupta & Campbell, 1995). According to Juran and De Feo (2010), prevention costs occur in order to minimize the appraisal and failure costs.

Moreover, the appraisal costs are costs related with maintaining the quality levels of the company (Feigenbaum, 1991). Or stated in another way, all costs expended to appoint if the activities are performed right at all times (Harrington, 1987). Sörqvist (2001) develops the definition of appraisal costs, stating that those are costs arise when verifying that right quality is delivered in all steps in an organization.

Failure costs are costs connected to the consequence of failure of meeting the requirement in the company and with the customer. The failure costs are divided into *internal failure costs* and *external failure costs* (Campanella, 1990). The internal and external failure costs are similar but differ in terms of that the internal failure costs include poor quality inside the company while the external failure costs include poor quality outside the company (Gryna, 1999). Further, the internal failure cost will only affect the company's organization while external failure costs causes problems for the customer in terms of inadequate products or services (Harrington, 1987).

Explained by Hwang and Aspinwall (1996) the PAF-model can further be divided into a macro and micro model. The macro model is based on the external customer and supplier relationship of an organization (Hwang & Aspinwall, 1996), while the micro model focuses on the internal customer and supplier within a department or a process. The micro model is similar to the macro model with the distinction that the whole organization is broken down in departments and section previous to its application (Winchell & Bolton, 1987).

Furthermore, the classification of CoPQ by Juran and De Feo (2010) is based on the PAF-model but with an important difference; the prevention and appraisal costs are excluded and *appraisal and inspection costs* are added, see figure 3.5. The appraisal and inspection costs refer to what Feigenbaum (1991) classified as appraisal costs, since inspection costs are included in the category. Further, Juran and De Feo (2010) exclude prevention costs in the classification but do not further elaborate on why. However, Sörqvist (2001) excludes the prevention costs since these costs are not considered to be a cost due too poor quality but an investment for good quality.

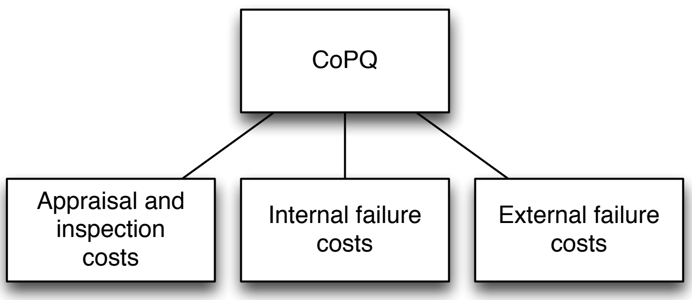

Figure 3.5 - The classification of CoPQ according to Juran and De Feo (2010)

Gryna (1999) expands the original view of internal and external failure costs by dividing the internal failure costs into *internal failure to meet customer requirements* and *costs of inefficient processes*, whereas the external failure costs are divided into *external failure to meet customer requirements* and *lost* *opportunity costs*. However, it is not clarified why internal and external failure costs are divided into subcategories, see figure 3.6.

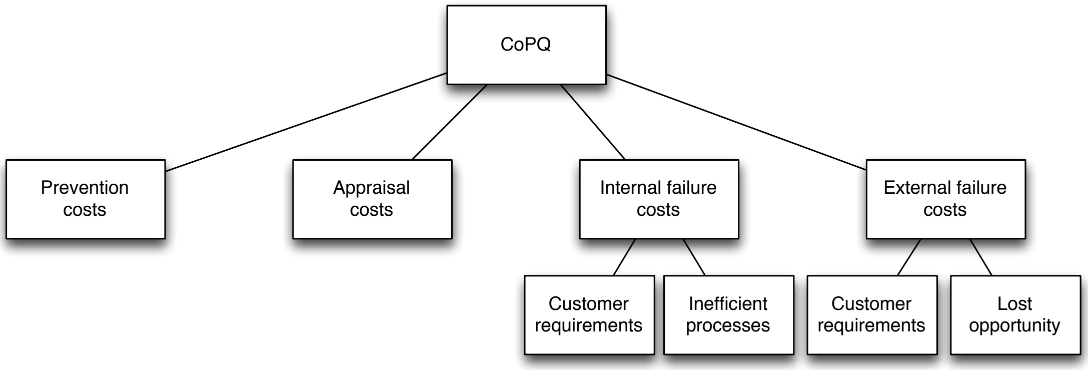

Figure 3.6 – The classification of CoPQ according to Gryna (1999)

Moreover, Giakatis et. al. (2001) expresses a similar view as Sörqvist (2001) which excluded prevention costs but with an important difference. Giakatis et. al. (2001) divides the prevention and appraisal costs into; *prevention losses* and *appraisal losses,* see figure 3.7*.* The argument to split it is due to that if the investments are successful the organization saves money, but if not the organization can lose the invested money and also cause further losses. Both Giakatis et. al. (2001) and Sörqvist (2001) shares the same view with the difference of that Giakatis et. al. (2001) expand on the idea and makes a distinction between good and bad investments, while Sörqvist (2001) states that prevention costs are always good investments.

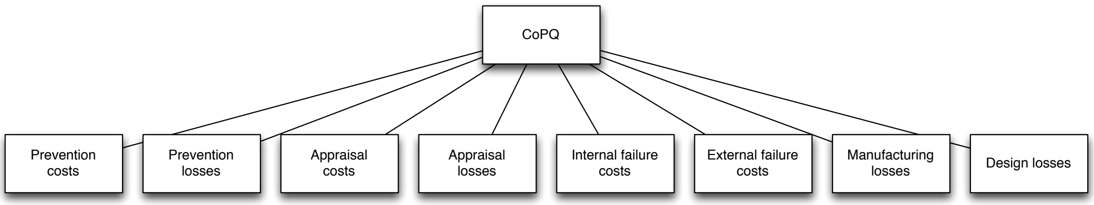

Figure 3.7 - The classification of CoPQ according to Giakatis et. al. (2001)

Giakatis et. al. (2001) further add two common losses; *manufacturing losses* and *design losses*. Those costs are generated in order to compensate for the occurrence of potential failure loss, and are large enough not to overlook in manufacturing companies. Manufacturing losses might be the cost of inefficient use of resources, whilst design losses might occur from that requirements on the product are sharpened which results in more expenses in order for the new requirements to be achieved.

Another way of viewing CoPQ is described by Modarress and Ansari (1987), see figure 3.8, which include two additional categories, *cost of quality design* and *cost of inefficient utilization of resources*, to the PAF-costs (Feigenbaum, 1991). Modarress and Ansari (1987) include those, because of their view that companies use Statistical Process Control (SPC), which is standardization of products to detect poor quality, and Just-in-time to improve the quality in the organization. Costs of quality design correlates with the SPC by reducing the manufacturing process, process control and product inspection, while cost of inefficient utilization of resources correlates to JIT with low utilization the quality costs are high.

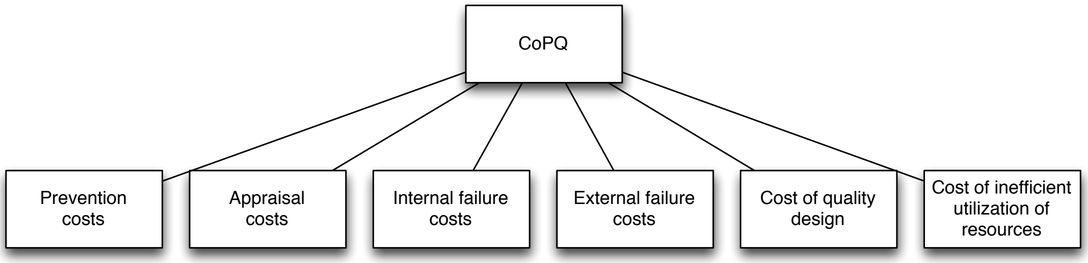

Figure 3.8 - The classification of CoPQ according to Modarress and Ansari (1987)

Harrington (1987) expresses another approach to classify CoPQ and divides those into *direct costs* and *indirect costs*, see figure 3.9. The direct costs and indirect costs are costs that Krishnan (2006) divided into visible and invisible costs (Krishnan, 2006). Invisible costs are not included in the different author's classifications (Juran & De Feo, 2010; Gryna, 1999; Dale & Plunkett, 1991; Sörqvist, 2001; Giakatis et. al., 2001), but instead mentioned as an important area to take into consideration.

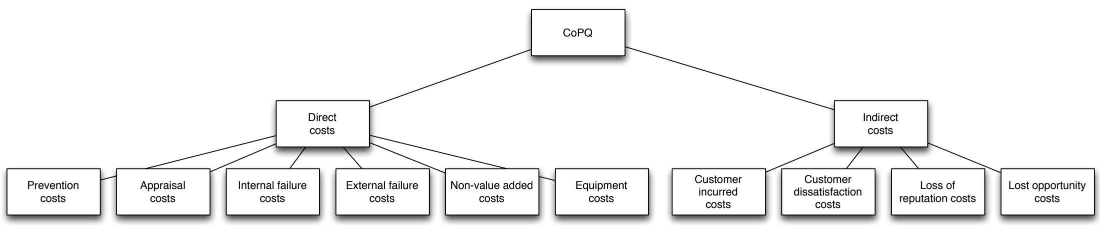

Figure 3.9 - The classification of CoPQ according to Harrington (1999)

Included in the direct costs are the PAF-costs (Feigenbaum, 1991), together with *non-value added costs* and *equipment costs* (Harrington, 1999). The reason for including non-value added costs is according to Harrington (1999) that ineffectiveness designed into the processes is more costly than problems created by the processes. The non-value added costs are activities, which are not related to the product that the external customer wants. Thus it is activities that creates no value to the customer but creates costs to the processes (Harrington, 1999). Equipment costs are costs to invest in equipment used for measuring, accepting or controlling a product and the space the equipment occupies (Harrington, 1987). Equipment costs are also mentioned by Feigenbaum (1991), but referred to as capital investments in quality information equipment constructed to measure product quality.

According to Harrington (1999) indirect costs can be divided into four major cost-categories; *customer-incurred, customer-dissatisfaction, loss-of-reputation,* and *lost-opportunity*. Harrington (1987) explains customer-incurred costs as the cost for when the output fails to meet the expectations for the customer. The customer-dissatisfaction costs arise when the customers are dissatisfied of the products or services, where bad quality level of a product results in lost revenue. Loss-of-reputation costs are more difficult to measure and predict than the other indirect costs. The costs affect the whole company and all products in a poor way and not only a single product (Harrington, 1987). The lost-opportunity costs arise when the company miss a customer order due to poor judgment or poor output (Harrington, 1999).

Dahlgaard et. al. (1992) has a similar view as Harrington (1987), by including visible and invisible costs in the classification. However, Dahlgaard et. al. (1992) chooses to classify it in a table where the costs on the one side is subdivided into internal and external failure costs, equally to Feigenbaum (1991), where prevention and appraisal costs is included and on the other side these costs are subdivided in visible and invisible costs respectively, see figure 3.10.

	INTERNAL COSTS	EXTERNAL COSTS	
VISIBLE COSTS	1	2	1+2
INVISIBLE COSTS	3	4	3+4
	1+3	2+4	1+2+3+4

Figure 3.10 - The classification of CoPQ according to Dahlgaard et. al. (1992)

Furthermore, another view of CoPQ is presented by Dale and Plunkett (1991) which involve a value-chain perspective to describe were in the value-chain different cost items occur, in order to give a clear picture where efforts have to be set. The view originates from the PAF-model (Feigenbaum, 1991) but is divided into *supplier/subcontractor, company/in-house* and *customer* by integrating those for each cost into a matrix. The reason for the division is to better connect the CoPQ with other business costs and make it easier for employees to identify the PAF-costs when using the matrix, see figure 3.11.

	Supplier	In-house	Customer
Prevention costs	P	P	P
Appraisal costs	A	A	A
Internal failure costs	IF	IF	IF
External failure costs	EF	EF	EF

Figure 3.11 - The classification of CoPQ according to Dale and Plunkett (1991)

3.3.3 Summarized theoretical framework

It has been found in the previous chapter that the authors give different views on classification of CoPQ. Therefore, the authors of this report have established a summarized framework.

CoPQ has been classified into the following categories; *prevention losses, appraisal losses* and *failure costs*, see figure 3.12. Included in each category, the value-chain approach stated by Dale and Plunkett (1991) will be used, in order to identify the source of the problems. Moreover, the classification will be based on the mix of the micro and macro model mentioned by Hwang and Aspinwall (1996). The micro model views the internal suppliers and customers inside the organization and not only the external suppliers and customers of the organization (Winchell & Bolton, 1987). However, the external suppliers and customers will also be considered when using this model and therefore a mix of micro and macro model will be needed.

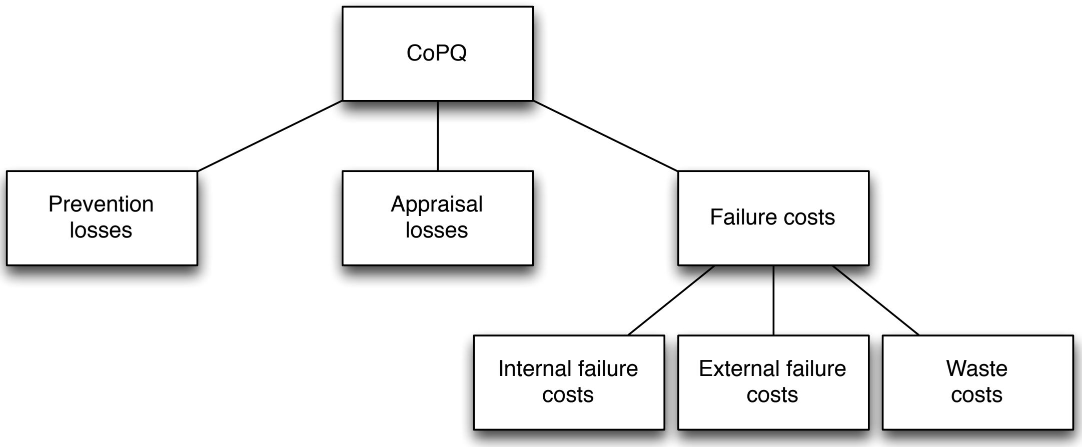

Figure 3.12 - Summarized theoretical framework

Further, the authors of this report emphasize that the costs that are unknown and immeasurable should be described as invisible costs, in consent with Gryna (1999) and Krishnan (2006). Further, the importance of invisible costs should be emphasized but excluded from the framework, but if invisible costs are quantifiable and measureable they should be included as either prevention losses, appraisal losses or failure costs. Thus, quantified and identified invisible costs will be included as visible costs and should thereby be measured.

The inclusion of prevention losses in the model is based on the argument from Giakatis et. al. (2001) where prevention losses are costs due to poor investments and prevention costs is investments for good quality (Giakatis et. al., 2001). Further, this is also strengthened by the classification of Sörqvist (2001), which exclude prevention costs because it is not considered to be costs as a result of poor quality.

Giakatis et. al. (2001) further emphasize that appraisal losses should be used based on the same argument as with prevention losses. This has been followed based on that not all appraisal costs are bad investment, but rather necessary in order to maintain an acceptable quality level. The appraisal losses are thus activities that are needed to have products and services with zero defects.

The failure costs are divided into the following subcategories; *internal failure costs*, *external failure costs* and *waste costs*. Internal failure costs are poor quality inside the company while external failure costs are poor quality outside the company, found by the customer (Gryna, 1999). In each of the classification mentioned above failure costs have been included and should therefore be used in this model as well (Feigenbaum, 1991; Juran & De Feo, 2010; Gryna, 1999; Giakatis et. al., 2001; Modarress & Ansari, 1987; Harrington, 1999; Dahlgaard et. al. 1992).

Harrington (1987) states that non-value added costs should be included as a part of CoPQ due to their major effect on the costs in an organization. This has been expressed by the other authors in different words, but with the same significance. Gryna (1999) uses costs for inefficient processes to describe non-value added costs, while Giakatis et. al. (2001) uses manufacturing losses and Modarress and Ansari (1987) states costs if inefficient utilization of resources as non-value added costs. Subsequently, non-value added costs should be included in the framework due to their importance and major use of this subcategory from the different authors. Further, the elimination of non-value added activities by improving processes can be described as the foundation of a Lean Philosophy, therefore should Lean Philosophy be included and thus the seven wastes (Womack & Jones, 2003). Therefore, the authors of this master thesis choose to define the non-value added costs as waste costs based on the seven wastes mentioned by Nicholas (2010); transport, inventory, unnecessary motion, waiting time, over-producing, over-processing and defects. The cost of quality design mentioned by Modarress and Ansari (1987) and design losses stated by Giakatis et. al. (2001) is by their definition similar to over-processing and will therefore be included in the waste costs category.

3.4 Use of CoPQ measurements

By conducting measurements of CoPQ in a company it is possible to change the mindset of the management and employees of the company (Harrington, 1987) or to create commitment from the management (Porter & Rayner, 1992). Measuring CoPQ can be used to transfer the effects of poor quality into monetary terms in order to visualize it for the management and for the employees, to make the employees aware of what the costs are (Hwang & Aspinwall, 1996). By doing this, there is a better chance that the management use the measurement instead of rejecting it (Dale & Plunkett, 1991).

Moreover, the measurement of CoPQ can be used as a motivation for operators and middle managers to display the cost items that arise in their department (Dale & Plunkett, 1991). However, for the employees to use measurement systems there have to be commitment from the management, otherwise it will not be used (Campanella, 1990). Further, if the measurements are not accurately done, the information from the measurements can be inadequate thus making it inaccurate. Consequently, there is a risk that the management will not actively use this information. However, to overcome this problem the company can start measuring only a limited number of cost items and later expand the measurement system (Sörqvist, 2001).

Further, the use of CoPQ measurements will also provide the company with a tool to identify problem areas and to prioritize (Oakland, 2003) and pinpoint where the potential improvements should be conducted (Roden & Dale, 2000). Although, some cost items, often invisible costs, are difficult to measure that creates an uncertainty for the company regarding how to relate to these costs (Sörqvist, 2001).

By using CoPQ gives the company a simple and understandable tool for measuring the effects of poor quality and the cost-savings from improvement work (Harrington, 1987). However, Dale and Plunkett (1991) state that comparison can be made internally between departments, but external comparison should be avoided. The difficulty of comparison is due to that companies choose to include different cost items in the measurement, or identify different cost items within different departments of the company (Harrington, 1987). Thus, each company needs to conduct their own CoPQ measurements to find the relevant costs (Hwang & Aspinwall, 1996).

According to Sörqvist (2001), it can be difficult to know which cost items to include as CoPQ. Cost items like re-work and reclamation can easily be classified as CoPQ, but other costs are harder to identify and more diffuse resulting in a grey area where each company has to make a decision regarding which costs to include. Though, cost items that are hard to define can beneficially be excluded (Sörqvist, 2001), otherwise cost items with no accordance to the company will be measured (Dale & Plunkett, 1991). Stated by Harrington (1987), all departments in a company cause problems and therefore it is equally important to include cost items from the manufacturing department as for the administration, where the administration can be referred to as invisible costs.

Early measurements of CoPQ results in less cost impact for the company and thus the company must strive to find the costs early to prevent major and expensive re-work and scrap together with possible dissatisfied customers or lost reputation (Harrington, 1987). Or as stated by Porter and Rayner (1992, p 70) "it costs less to reject faulty material at the goods inward stage than it does to scrap a manufactured item that has had the faulty material incorporated into it". Krishnan (2006) further states that the invisible quality costs tends to increase as a ripple effect downstream in the chain, due to that problems caused in one department will result in extra work in another.

The categorization of the cost items can be a problem since a quality-related activity can often be included in different categories (Bamford & Land, 2006). An example of this is given by Oakland (2003) where a design review can be considered as a prevention cost, an appraisal cost or a failure cost due to how and where it is used in the process. Stated by both Oakland (2003) and Porter and Rayner (1992), it can be difficult to measure the prevention costs. Since all well-managed organizations try to prevent quality problems it is hard to separate prevention activities from prevention quality-activities. This means that the organization has trouble of knowing what to include or to exclude when to measure prevention costs.

Finally, it is important to know that only measuring CoPQ will not resolve the problems of a company, instead it will only give a view on what activities that need to be done in order to improve the quality level of the company (Harrington, 1987). Measuring CoPQ can been seen to be reactive, only reacting on the problems measured and monitored by the organization and not being proactive and act before the problems occur (Elsen & Followell, 1993). Further, if a company measures high CoPQ it should not be considered to be negative for the company, instead it is a proof of that the company has a useful measurement methods that reveals most of the cost items (Sörqvist, 2001).

4. Empirical findings

The empirical findings describe the overall process from signing a contract on a product to delivery to the external customer. Further the two manufacturing department in focus for this study; the cable-manufacturing department and the system-installation department will be described. The internal customers and suppliers to the manufacturing departments are described thereafter.

4.1 Introducing process description

A customer order passes the following main functions in the company; sales, project management, R&D, manufacturing and final test. The purchasing department, material management and incoming inspection and storage support the main functions. The process is managed and monitored by a project team, see figure 4.1. The main functions are further divided into operating departments, where each department has the economical responsibility of reaching a financial balance.

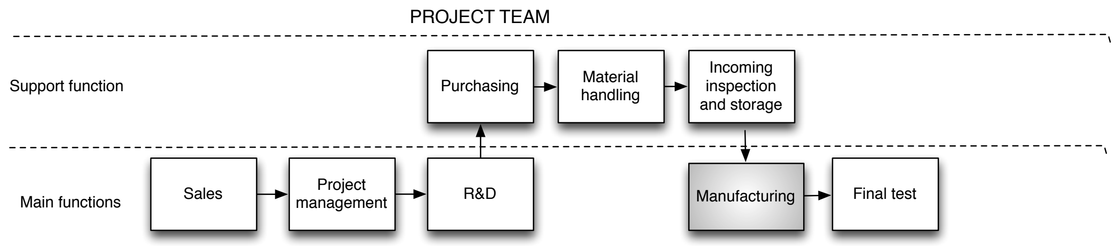

Figure 4.1 – Overall process description

The sales department is responsible for the sales and order specification from the external customer. In the contract, all customized features are specified and a delivery date is set. The contract is often specified in cross-functional teams, involving employees from the sales department, project managers and R&D managers. Each customer order generates one project team, created by the project management department. The project team is responsible for the order to be delivered to the external customer in time and in meeting the right specifications. Further, the project team is responsible for resource allocation and prioritization of activities. Before the project starts, a budget is established from a time and cost estimation, based on experience of previous similar projects. The project plan is set based on required time and cost for each department. A project manager, supported by sub-project managers located in the functional department, runs the project. The average time for delivery of one product is 15-18 months.

When the budget and time schedule for the project is established, the R&D department is responsible for developing the final product and specifying all required material, drawings and instructions. Material sourcing is managed by the supporting function purchasing, responsible for negotiation and signing contracts with the suppliers based on the requirements from the R&D department. The supporting department material planning is responsible for the assuring that materials are available at the storage when the manufacturing starts. The incoming material from external suppliers is delivered to a main storage, where the employees of the storage are responsible for performing an incoming inspection of the incoming material and for picking the required components and send it to the manufacturing department. Some of the components in the final product are manufactured in-house and the rest is purchased from external suppliers. After the final step in the manufacturing process, the product is sent to the system-testing department for a final test before the product is sent to the external customer.

4.2 The manufacturing function

The manufacturing is divided into cable manufacturing, system installation and four other departments, denoted A, B, C and D, see figure 4.2. All departments manufacture components used in the final product, which is assembled in the system-installation department. Since the cable-manufacturing department and system-installation department is the scope of the project, those departments will be more thoroughly described.

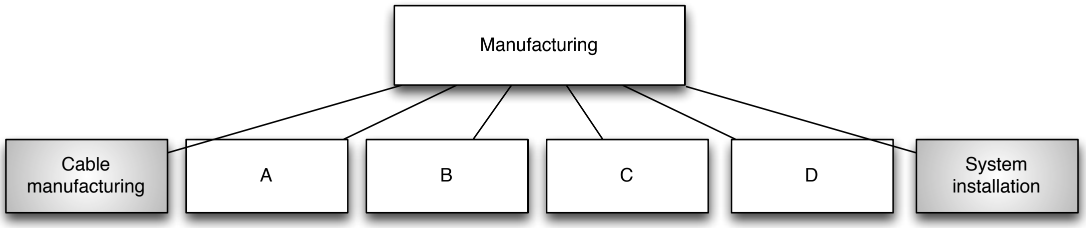

Figure 4.2 - Operational departments of the manufacturing function

When the order reaches the manufacturing department, the product should be ready for the first operation, and all materials should have been sourced and the documentation should be prepared. The manufacturing departments are monitored according to a JIT-system, meaning that the products should flow through the manufacturing process without any buffers. The different roles and responsibilities of the employees in the process are described below.

Manager: The manager has the overall responsibility for monitoring the department regarding the products and the employees. This includes prioritization of assignments and economical responsibility of maintaining financial balance.

Production engineer: The production engineers are responsible for solving problems and deviations when they occur in the daily work of the manufacturing process. Further, the production engineers are responsible for prevention work and monitoring error-reports.

Production planner: The production planners are responsible for production planning and monitoring of assigned work-centers. This includes the responsibility of breaking down manufacturing plans to daily activities, starting and stopping orders in the production according to the capacity, and monitoring the resource utilization and re-plans when production disruptions occurs. The production planners are further responsible for ensuring that material and components are ordered from the storage when required in the production.

Operator: The operators are responsible for the sublimation of the product, both regarding new products and upgrading of sold products.

Inspector: The inspectors are responsible of inspecting the products, assuring that the products are manufactured in the correct way. The inspections are performed both during and after the product is manufactured.

Material planner: The material planners are responsible for product planning and monitoring of assigned products. This includes the responsibility of ensuring that materials are available at the right time in order for the production to start. The material planners belong to the supporting function material management, but are involved in the daily planning of material for the manufacturing department.

4.2.1 The cable-manufacturing department

The cable-manufacturing department manufactures cabling-systems for transmitters, receivers and power distributors. All cabling-systems are unique, designed according to required customer features. Approximately 600 different types of cabling-systems can be manufactured of various size and complexity. The throughput time fluctuates between a couple of hours to 300 hours. The cable-manufacturing department has two major responsibilities; manufacturing of new cable-systems and reparation and upgrading of old systems.

There are two managers responsible for the cable-manufacturing department. Other main roles are production engineers, production planners, operators, inspectors and material planners. The process flow of the cable-manufacturing department can be described in the following three steps; order planning, manufacturing and control, see figure 4.3.

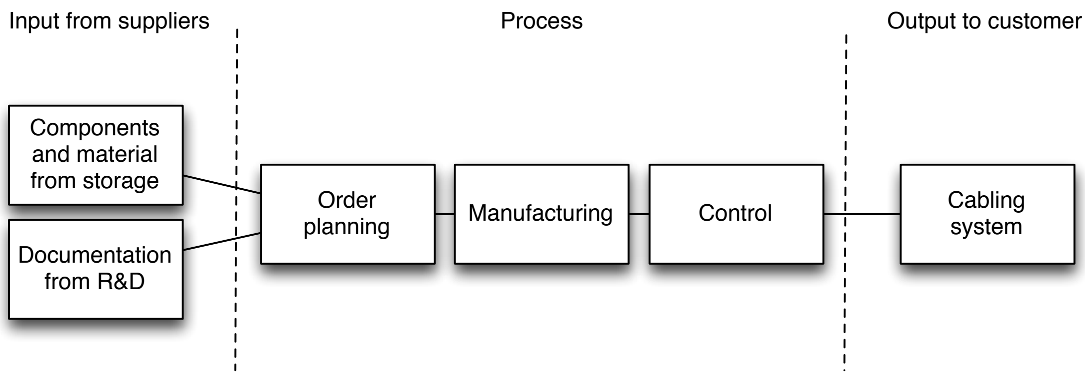

Figure 4.3 - Process flow of the cable-manufacturing department

Order planning. Jobs to be performed by the cable-manufacturing department are visualized in the computer planning-system, showing planned date for initiation of a job. In the computer-system, the final product is hierarchically broken down in sublevels, describing different operations and required operation time. The computer-system further triggers an order list, which includes all required components the R&D has declared needed. When the production planner receives an order, it is controlled if it is "error-free" according to the three instruction areas;

- Material – all materials are purchased and available at the storage
- Documentation – all documents, instructions and drawings from the R&D department are available and complete

- Resources – the correct amount of resources in terms of time and funding is calculated

If the order is correct, the production planner releases the order in the computer- system, whereupon an inbound delivery of the required material is ordered from the storage. Next, the production planner assigns the job to one of the operators. The assignment is based on availability and experience of the operator. Often, the order is inadequate when it reaches the production planner. The most common problems the production planner discovers are that materials are not available in the storage or that the order is re-planned by the material planner without their knowledge. In both cases the production planner contacts the material planner, which in turn further investigate the problem.

Manufacturing. The operator opens the job in the computer-system where the complete cabling-system is broken down in foreseeable operations, called operation cards. The operation cards, physical drawings in combination with instructions and CAD-drawings help the operator to manufacture the product in the correct way. Most often, one operator works with one cabling-system. Each operator has a working area, including an assembling table, a computer and tools. Most of the operations are manually performed, only a few are automated. Documentation from the R&D department controls the design and installation of the cabling-system. The operators have general competence regarding manufacturing of small and large cable-systems and further for building new systems and upgrading of old systems.

In some cases the operators themselves cause problems, such as incorrect assembling. In those cases, an error-report is specified in the error-handling system where the operator specifies the problem according a certain error-code, describing the nature of the problem and what caused it. If the problem is considered to be minor and can be solved by the operator it will be directly fixed, but if it is a major error not manageable by the operator, the production engineer will be contacted in order to help solving the problem.

The most common problems described by the cable-manufacturing department are problems with incoming material from the storage, or inadequate documentation from the R&D-department. In this case the operator error-report whereupon the production engineer automatically receives a mail with the error-handling order. Thereafter, the production engineer judge if the problem is caused by an internal or external supplier or by the cable-manufacturing department itself. The production engineers are responsible for audit all specifications and to document of how the problems have been solved, which will be the basis for the quarterly financial balance and for future improvement work.

One of the most common problems caused by internal suppliers are problems with incoming material from the storage. Common problems discovered by the operators regarding incoming material from the storage are incorrect incoming material, incorrect number of incoming material, delayed deliveries or damaged components. If the cable-manufacturing department has received incorrect numbers of components, the production engineer contacts the storage whereupon a new delivery of components is made. If the external supplier on the other hand has caused the problem, the production engineers email a reclamation to the storage, which in turn contact the purchasing department. The purchasing department is in turn responsible for the contact with external suppliers. In this case, the assembled product is either set aside meanwhile waiting for new components from external suppliers, or another part of the product can be assembled. In some cases when the lead-time from the external supplier is long and there is a shortage of time, the product is sent to the engineering workshop, which is an external department that helps fixing defected components. The sub-project manager decides if the product should be sent to the engineering workshop.

Case example: Incorrect screws from external supplier

One of the operator discovered that one of the screws did not fit in the cabling system. The operator contacted one of the production engineers to solve the problem. Neither the operator, nor the production engineer knew weather the problem was caused by a faulty design or by the external supplier, whereupon the R&D department was contacted. Two of the designers looked at the problem, concluding that the problem was caused by the external supplier. This process took approximately two weeks. Problems with external suppliers are handled by the purchasing department, whereupon the purchaser of the material was contacted. The purchaser did in turn contact the external suppliers, and the negotiation of having the supplier responsible for the problem took additionally four weeks. Meanwhile, the production planner was responsible for re-planning the manufacturing process; including put the operator in a new job and informing the sub-project planner that the manufacturing of the specific product was stopped.

Another common problem occurring in the cable-manufacturing department is inadequate or missing documentation from the R&D department. Common problems are that designs are incorrect, components and parts are not compatible, drawings are unclear and that instructions are inadequate. When problem regarding inadequate documentation occurs the production engineer separates released orders from active, where released orders are old projects that has previously been funded for a project that is finished, whilst active orders that are ongoing project. If the product is released, the order is considered being finalized and accurate to use in any order without changes, while the active orders are currently developed or re-designed from the R&D department.

Problems concerning released orders are discussed at a daily meeting with the production engineers, meeting leaders and designers from the R&D department. After the meeting the production engineer and one or two designers, depending on if it is an electronic- or mechanical problem, visually inspect the product before deciding on how to proceed. If there is a problem caused by the R&D department, the problem can either be solved directly or in some cases it requires a couple of days. In some cases, the R&D department informs that another supplier has caused the problem. However, the solutions are only “quick fixes” where no changes are permanent. Due to that the changes are not permanent, many of the problems are never solved, therefore commonly reoccurs in the next manufactured cabling-system.

When a problem occurs for a released order, operator can usually work with another part of the product in waiting for a decision from the R&D department. The lead-time for a decision and for correcting a problem is fluctuating between one day and a couple of weeks, depending on the complexity of the problem. If the problem is severe and no solution is given before it is critical for continued work, the product is stopped and the order is visualized in a so-called "stop list". Thereafter, the operator needs to work with another order until the problem has been solved which causes the production planner to release a new order to the operator.

If a problem occurs for an active order, the production engineer directly contacts the responsible designer or sub-project manager. Further, the product is set aside and visualized in the "stop list" and a change order is created, which is an order to change either the design or the documentation. The change order results in a re-planning for the production planner and re-work of the product.

After the entire cabling-system is built, a so-called after-meeting is held, where it is decided if the solutions of the problems should be permanent or temporarily. Participating in the meeting is the production engineer together with the managers of the cable-manufacturing department, and representatives from the quality department, industrial engineering, R&D, and the sub-project manager. If the solution is to be permanent, a re-design needs to be made; therefore it is during the meeting decided who will fund the re-design. The opinion of who should fund the redesign is often divergently.

Control. Continuous inspections are done during the manufacturing, performed by an inspector. The inspections are made before the operator seals the system with a capsule, critical for continued work. When the control is supposed to be performed is specified in the operation cards.

"We struggle with the question: "What is good enough?" For instance, a cable cannot be too short, which will make it to tense, nor too long, which will make it to flexible. Everything is not controlled by installation prescriptions."

Case example: Changing thickness of cable
One of the operator discovered that a cable did not fit in the cabling system due to that it was considered being to thick. The operator contacted one of the production engineers to look at the problem, whereupon the production engineer contacted the R&D department and the responsible designer re-designed the cable into being thinner, and the cabling system was manufactured. The new design was used in another cabling system, at a later time, which was built by another operator. According to this operator, the cable was to thin whereupon the production engineer was contacted. The same procedure happened two more times, and the final design was the same as the original thick cable.

The inspectors perform a final inspection of the product before the product is delivered to an internal supplier, where the product is inspected according to a checklist. The purpose is to ensure that the cable-systems are assembled in the correct way. The operator can resolve most of the problems discovered, and in other cases the inspector contacts the production engineer.

"Most of the problems we have are recurring, origin from the R&D department. It is often the same problems that are found in the inspection during sublimation and in the final inspection."

After the final inspection, the cabling-systems are delivered to the next internal customer in the value-chain; the system-testing department. In some cases, the product is sent directly to the system-installation department. The system-testing department connects the system and tests the interaction between the transmitter and receiver in certain reference points before it is sent to the system-installation department.

4.2.2 The system-installation department

The system-installation department is the final step in the manufacturing process, where the two land-based products are assembled. Both the software and hardware differs depending on required customer features, which makes each final product unique. The average throughput fluctuates between 700-1700 man-hours. The department has three operating areas;

- Assembling - assembling of the final product,
- After sales - repairing, serving and upgrading of old systems
- Travelling consultancy - repairing, serving and upgrading systems at the customer site

The system-installation department is staffed with one manager, production planners and production engineers. In addition, the department includes a fluctuating number of operators. The process flow of the system-installation department can be described in the following three steps; order planning, assembling and control, see figure 4.4.

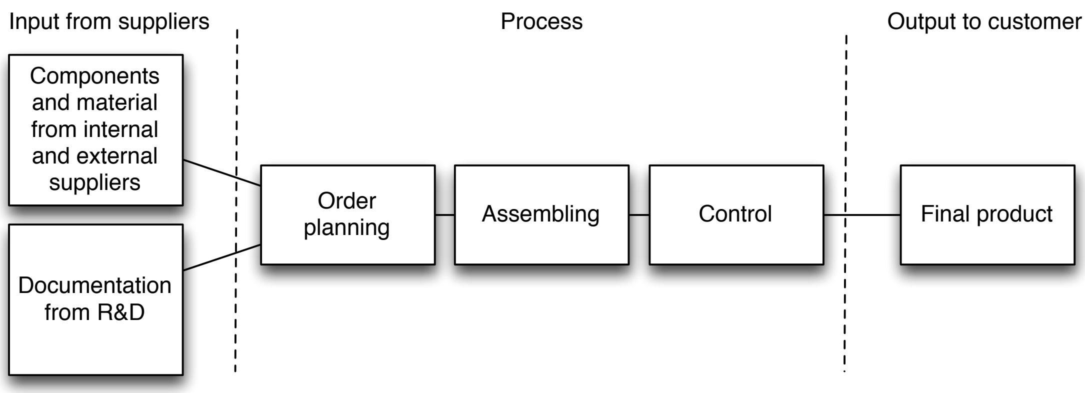

Figure 4.4 - Process flow of the system-installation department

Order planning. A new job is triggered from an order in the computer-system, which break down the job in sub-levels. The system generates an order list specified from the R&D department, including all required resources. This includes time for the job and materials and components from internal and external suppliers. The external customers are as well suppliers to the system-installation department due to that the external customer sent computer systems to be integrated in the final product.

When the order is released from the production planner, the required material and components for the first operations are ordered from the storage. The storage is responsible for picking and delivering material from both internal and external customers. Since the final installation includes operations spread over 700-1700 hours, the production planners plan and order the delivery from the storage in different batches, not to make the components take too much floor space.

Assembling. One final product is assigned to a work-team consisting of three operators; one being the overall responsible for the product, responsible for reporting deviations and serving as a contact person.

The floor of the system-installation department has a functional layout consisting of working areas marked as squares in which one product is assembled. Operations are divided into so-called work-packages, which break down and gather a number of operations in a manageable amount. The work-packages contain work-cards instructions and CAD-models helping the operator to assemble the product in the correct way. The foundation of the final product is a chassis and a cabin in which the interior design of the product is installed. Most of the hardware is purchased from external suppliers, and the software from internal suppliers, although, each component is specified from the R&D department. The final product consists of separable assembling flows, meaning that if disruption in one of the flows, assembling can always be performed in another part. The most critical component for the assembling is the cabin, in which the other components are assembled. Mechanical problems and delays are considered being the biggest problems in the system-installation department.

Delays of components and materials are caused from three main sources; delays from external suppliers, delays from internal suppliers and delays of systems from the external customers. The external customers supply the company with specific computer system, meaning that the customer also serves as a supplier. Further, problems with poor quality of incoming material are a critical problem. If delays or problems with incoming material occur, the production planner contacts the storage.

Problems depending on external suppliers and inadequate documentation from the R&D department belong to the most common mechanical problems. Another problem is that many of the drawings are considered not to be manufacturable. When deviations of less complex nature occur, the operators most often solve the problems within the team. If the operator discovers a problem caused by the R&D department, the operator directly contacts the responsible designer, who either looks at the problem or directly supports the operator by telling how the problem should be solved.

"Each part is perfectly designed, but it does not work together as a system due to lack of compatibility"

Many of the problems and deviations occurs origin from that all products are customized; therefore a unique system is built for the first time.

"Since all products are unique; some operations might have to be re-assembled 2-3 times since the operators have never done an equal job before. It is therefore very hard to plan and allocate the resources."

Another major problem is that re-designs of the systems are made from the R&D department during the manufacturing process. Re-designs results in a change-order, causing re-planning and re-work. Since the operators can work in parallel flows, the operators can occupy themselves with other types of work, but the change in workflow causes confusion regarding what operations that have been performed. Further, the complexity of the product causes operations to be forgotten during the process. In addition, the final products are considered to be hard to service since the product has to be disassembled in order to be serviced.

"A big problem is that the design is not done when we start manufacturing. This means that if something is changed, we have to re-assemble parts in order to fit the new design."

Further, many of the problems are recurrent, and problems that should have been solved by the R&D department are not changed. If the same problem occurs, most often the previous project funding the design is finished; therefore no one funds the change of the re-designs.

"I think we are struggling with the same problems today as we did a decade ago."

Other problems and disruptions are a consequence of limited space. Often, when prototypes or other test operations are performed the area of the installation hall is used. This results in parts getting mixed up and *"everyone fights over the same small area".*

Case example: Space planning
Products that are assembled often need to be moved in order to make space for vehicles to be upgraded or serviced, which causes a disorder in the layout. When vehicles are moved, three people are involved; one drives, one delegates and one move tools and other things occupying the lane. This in turn causes disorder in the moved product, not only due to that operators gets occupies, but also due to that tools and components are dis-assembled.

If a problem occurs, the operator manually writes the deviation in a journal. Meanwhile waiting for a decision, the operator can assemble another part of the product, since the product consists of separable flows of operations. Many of the problems occurring are fixed directly by the operators, are never reported. The operators consider it being easier to fix the problem right away than to error-report. In some cases the production engineer is contacted for helping to solve the problem.

"There are many employees at the quality department, but they are never here. What is their job? We see very little results and never get any feedback from any reporting."

Morning meetings with each ongoing project are daily performed with the project managers, designers, sub-project managers and production engineers in order to highlight deviations and problems. The sub-project managers get a copy of the deviation journal in order to follow-up problems concerning other departments. In the end of each project, the production engineer or the sub-project leader compiles all manual deviation reports into the error-handling system. If the operators themselves cause the problem, the problems are almost never reported.

"A new installation can have up to 500 deviations of different kinds. An approximated estimation is that 20 percent of the deviations are never reported."

The system-installation department has two other operating areas; after sales upgrading and repair and travelling consultancy. When an old system is to be upgraded or repaired, the product enters the system-installation department, whereupon the product is disassembled, and the parts sent to the concerned department for further upgrading. When all systems are upgraded, the components are sent back to the installation department for final assembling. Jobs where systems are to be repaired, upgraded or serviced are often ordered from the customer on short notice, which not only disrupt the original workflow and occupies space, but also causes problems in planning for resources. In some cases the repair is made at the facilities of the customer, which is referred to as travelling consultancy. In this case, a number of operators is sent to the customer. This in turn leads to that another operator has to take over the job for the original operator.

"One of the hardest thing in the daily work is to take over someone else's job. There is a very high risk of making simple mistakes, since you do not know what is done and what is not done"

Control. Before sending the product to the customer, an inspector performs a final inspection. There are no continuous inspections performed during the assembling.

"It would be good to have inspections during the assembling, but the culture in the department is that you do not want to be controlled. It is a professional pride in not making any mistakes."

After the final control, the product is sent to the system-testing department where the complete system is tested in field.

Case example: Updating of serial number list
All final products includes a serial number list, containing all components included. This list is further supposed to be delivered to the final customer. During the process, a number of re-designs and upgradings cause changes of components, which should be updated in the serial number list. Before the delivery to the customer, this list is not always updated. In order to quickly fix the list, employees from the system-installation department and the system-testing department needs to get involved for fixing the list, which involves employees from both the system-installation department and the system-testing department.

4.3 Internal customers and internal suppliers

In the following section, the internally involved departments and functions, affecting the cable-manufacturing department and the system-installation department are described. The departments can act as either internal suppliers or internal customers, see figure 4.5.

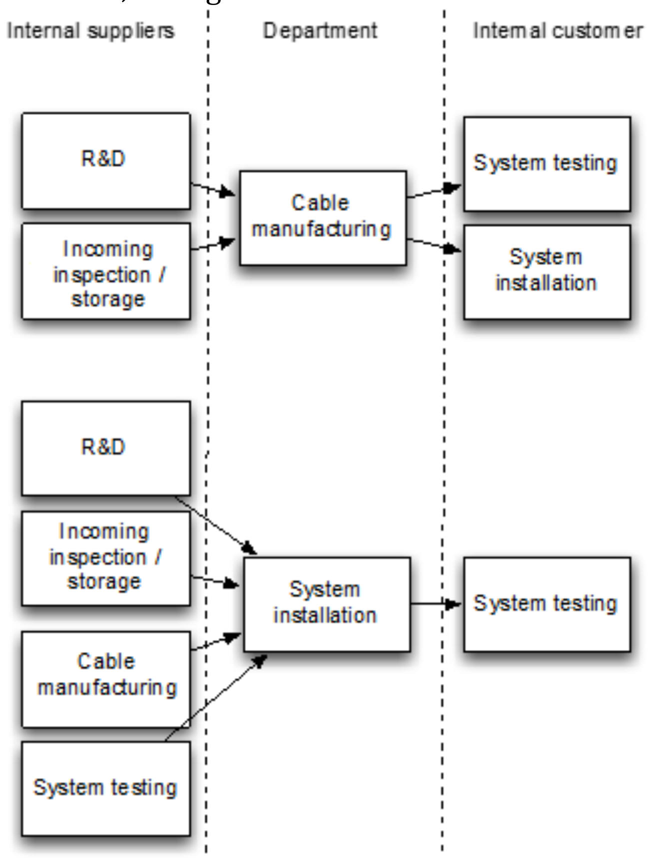

Figure 4.5 - Internal suppliers and customers for the manufacturing department

4.3.1 The R&D department

The R&D department is responsible for the research and development of all products, divided into three main areas; hardware design software design and mechanical engineering.

When a product is designed, the R&D department is responsible for specifying all required documents for the manufacturing department and the purchasing department. This includes all required materials, drawings, instructions and documentation for a specific operation. The specifications further include tolerances, quality standards and number of components required, which is the basis for future negotiations with external suppliers, performed by the purchasing department. Setting too tight standards results in those suppliers to terminate the contract, which is considered being a problem.

When a new project start an old project or product is copied in order to make an estimate regarding time and cost. The designers open the project in the computer-system, viewing the project at an overall project-level. In this case, the designer can only find error-problems and deviations reported from the project, and not from the product. This is due to that the computer-system and the error-handling system from the manufacturing function are not integrated; therefore the error-reports cannot be viewed. The R&D estimate cost and time depending on the reported deviations and problems from the previous project, without the taking consideration of the error-handling reports from the manufacturing department. Consequentially, previously reported problems are neglected, leading to that the time and cost estimations are often incorrectly based on "gut-feeling-estimations". Therefore, the time frame is tight and the R&D department has to deliver partly finished documentations to the manufacturing department. Either the manager of the R&D department or the project manager decides when the project is delivered, or the opinion might differ between those stakeholders.

"The project decides that we are finished with a design even though we are not. We don't have any other choice but to deliver half-finished documentation to the manufacturing department".

> Case example: Fire-fighting with prototypes
> Fire-fighting solves many of the problems arising. In cases when shortage of time, a prototype of a specific component is used in the beginning of the manufacturing process. The component is changed in the end of the manufacturing process before delivery to the final customer but this is considered to be hard to manage and control, therefore often forgotten to be changed on the way and thereby delivered to the customer.

A common problem for the R&D department is that the R&D department not cause all problems reported from the manufacturing department.

"We often participate in sorting out which problems are caused by us, by the manufacturing department themselves or by a supplier. This is very frustrating and

time consuming. One would think that the competence should exist in the manufacturing department".

Historically the manufacturing department has solved problems by themselves, but due to restrictions in the manufacturing department the operators are not allowed to modify solutions without having a document from the R&D department.

"During the last project, the manufacturing department made some kind of magic, but this time they can't or won't. It is hard for the operators since they do not know how things work. They do not know the difference between a deviation and an improvement suggestion."

4.3.2 The purchasing department

The purchasing department is responsible for the product range and the supplier contracts; further for placing orders, monitoring deliveries and the daily contact with external suppliers. The procurements of products are evaluated from the four parameters; price, performance, quality and brand strategy. Currently, the purchasing department is pressured by cost saving initiatives from the management, meaning that price is a critical parameter. An evaluation of the suppliers is performed monthly by the purchaser based on delivery precision and quality problems reported from the incoming inspection.

When the development of a new product is finished, the R&D department registers the required material and complementary specifications in the computer-system. The specifications are the base for the procurement process performed by the purchasing department. Long lead times from the suppliers are considered being a big problem, due to the time pressure from the project plan. Often, the lead times are longer than the time allocated for procurement and purchasing. If more than one product is planned to be built on the same customer order, the purchasing department order components for all systems in order to overcome the long lead times.

"Since we are project-driven, often "panic solutions" are made, and the project does not want to pay for any change-costs."

Further, a problem for the purchasing department is the low quantity of purchased components, which causes a low bargain power towards the suppliers. Another problem is that the specifications set by the R&D department are often hard for the suppliers to meet.

"It is important for the R&D department to make suitable specifications that the suppliers can actually meet. The specification seems to be set based on old habits, which sometimes is too tight".

If quality problems caused by external suppliers are discovered by the manufacturing department, the purchasers are responsible for contacting the supplier. Reclamation to the supplier is performed, including negotiations regarding delivery of a new product and compensation for downtime. The outcome of compensation for downtime is considered to be low.

Case example: Non-reporting of problems
In stressful situations in the manufacturing department, defected incoming products are sent to the engineering workshop for quick fixes. In these cases, the problems with the incoming products are not reported to the purchasing department. Consequently, the lack of knowledge leads to that the next time the product is purchased, specifications are not corrected or updated and the same problems occurs again.

4.3.3 The material management department

The material management department is responsible for the material planning; including the responsibility of assuring that materials are available at the storage when the manufacturing starts. Each material planner is either responsible for a certain project or a certain product family.

When the material planner receives an order, the project team provides a time plan for the project. The material planners enter the final products in the computer-system, which in turn breaks down the products into the final components. The responsibility for the material planner is thereafter to monitor the order, assuring that all materials are purchased and available on time at the storage.

The most common reasons for why materials are not available on time for the manufacturing to start are considered to be that problems and deviations are discovered in the incoming inspection and storage. The most commonly discovered problems are incorrect purchased materials, incorrect design, problems from external suppliers and non-compatible components. This causes delays, since problems result in materials that need to be sent back to the suppliers or internally re-designed. Consequently, this in turn causes re-planning for the order. Another common problem is that the quantity of available components in the storage is incorrect in the computer-system.

Case example: Early specified delivery date
The suppliers has specified a specific delivery time for purchased components to be delivered. Due to lack of time, the components are required at a "wanted delivery-date" before the set delivery date. The material planners enter the wanted delivery-date in the computer system, which cannot be met and consequently the complete order is delayed.

When problems occur, the material planners contact the production planners of the manufacturing department, in order for them to re-plan the manufacturing. Bigger problems are handled by sub-project managers, which are authorized to prioritize activities. If problems and delays occur, often required components are borrowed from another project.

4.3.4 The incoming inspection and storage

The incoming inspection and storage is separated from production site and located 20 kilometers away. The incoming inspection and storage is responsible for performing the incoming inspection of products from suppliers and further for stocking components required for the manufacturing process and spare parts for the customers.

When an incoming shipment from an external supplier reaches the storage, the packages or pallets is visually checked for damages and the delivery notes are inspected. Thereafter the goods are sent to the incoming inspection, where an inspection is made if the goods meet the specification made by the R&D department. The inspection is manually performed, by using tools for measuring and visually checking for damages and scratches. The inspections are made from random samples, but historically problematic materials are inspected more frequently. The two most common problems with the inspected components are inadequate measurement specification, and requirements to the external suppliers from the R&D department. After the incoming inspection is performed, the components are sent to the storage whereupon the components are stored in shelves.

Fluctuations in demands and re-planning from the material planners is consider being a major problem, causing re-work and high fluctuation in workload for the employees. The incoming inspection and storage department therefore strives for creating an even flow of demand, but most orders tend to be placed in the beginning of the week. Further, orders often are re-prioritized from the project managers, causing un-even flow.

The most common reasons for components to be sent back from the manufacturing department are due to un-wanted need and reclamations. The unwanted need is caused when the material planners create and initiate a need in the computer-system, which is not required in the point of time. This can be a consequence of re-planning or that components used for prototype building are sent back. Incorrect order picking, design problems or other deviations most often cause reclamations. Incorrect order-picking can be a consequence of that the purchasing department purchase components belonging together in different batches causing that all required components are not available. Deviations can be caused by external suppliers, but often from internal suppliers. Often this is caused by two components, which are correct according to all specifications, but not compatible when assembled.

"In cases when two materials are not compatible, we send it back to the manufacturing department. How can we complain to the suppliers, when all specifications are met? We do not handle R&D problems."

Other problems caused by internal suppliers are inadequate communication between the departments, and response for e-mails and phone calls often have a long lead-time, which causes stop in the flow and occupies floor space. Communication problems with the incoming inspection are most common with the R&D department and the purchasing department.

Case example: Box of mixed components
A box consisting of six different components was delivered to the incoming inspection. The components were in turn supposed to be assembled into two major spare parts. The inspector did not know which components belonging to which spare part, whereupon the R&D department was contacted. It took approximately two weeks for the R&D department to send an email back, describing that the purchasing department have incorrectly purchased those components in one kit, and the purchasing department should answer which components that belongs together. The inspector sent the problem forward to the purchasing department. This is currently an ongoing problem, and two weeks after the email was sent to the purchasing department, no answer was received, and the problem is still not solved.

4.3.5 The system-testing department

The system-testing department is responsible for connecting and testing the systems before the installation of the final product in the system-installation department. Further, the department is responsible for making the final test of the product before delivery to the external customer. The system-testing department receives products from both internal and external suppliers, where the main internal supplier is the cable-manufacturing department. When a cabling-system is delivered from the cable-manufacturing department, the system-testing department tests the interface between the transmitter and receiver in certain reference point. If the interaction is inadequate, the system-testing department is responsible for troubleshooting the cabling-systems. Incorrect cabling and incorrect placed connectors dominate the most common problems.

Case example: Problems of troubleshooting
An incoming cabling-system showed errors in the interactions when tested. The time taken for troubleshooting was 30 hours, showing that one cable was incorrectly connected. This consequentially caused the system testing a calculation difference of 30 hours.

Before the product is tested, the system-testing department makes a control of the product, looking for outer damages and common assembling mistakes. The control is performed due to historical bad experience of common problems.

"We do not trust the internal suppliers. Sometimes it almost gets personally. If we don´t make the control of the products from the cabling manufacturing department, it is likely that something for 100 000 SEK breaks during the system-test".

A deviation list is delivered with the products from the internal suppliers, including all problems and deviation following form the previous department. Often, scratches and defects from previous departments are not fixed when the product enters the system-testing department.

"We are considered being some kind of "fix-it"-department. It causes a lot of extra time to fix problems caused by previous departments."

4.3.6 The engineering workshop

The engineering workshop is responsible for prototype building, but has become a workshop for correcting problems in the manufacturing department. In cases when there is a shortage of time, the defected components from other department are sent to the engineering workshop.

The most common jobs assigned to the engineering workshop are design-related problems from the R&D department and assembly problems from the manufacturing department. The production planner or the sub-project manager is responsible for deciding what problems that should be sent to the engineering workshop.

When a job is performed, the time for correcting the problem is registered in the computer-system. The time is connected to the error-report from the manufacturing department, but a further description of the job is not documented.

"We used to have a list of the jobs we performed, which everyone called "the black-list". We do not have that anymore, since someone was always blamed for being the black sheep."

The manager and the production planner, which determines whether the problem will be solved before the supplier, plan the jobs assigned. If a job needs to be performed quickly, overtime compensates the time pressure if needed. Many of the problems are constantly recurring, most of those problems origins from the R&D-department.

"We get the same problems today that we got fifteen years ago. Problems are never corrected."

Case examples: Design problem causing assembly problems
Five years ago, a common problem was sent to the engineering wokshop; one of the sides of the cabling-systems, named the doghouse, had the incorrect design. The design problem caused assembly problems in the manufacturing department, causing cracks when screws were tightened. It took five years, and a number of broken cabling-systems in the engineering workshop before the problem was solved from the R&D-department.

4.4 Summary of the problem situation

All problems described can be summarized in cost parameters, presented in table 4.1. The problems are described from the perspective of the manufacturing department, and can be seen as generic for both for the cable-manufacturing department and the system-installation department. Further, the extents of the problems are expressed in different ways since the departments are positioned in different stages of the value stream. The most common problems described in each department can be found in appendix VI.

Table 4.1 - Summary of the most common problems in the manufacturing department

Problems	Explanation
Quality problems caused by external supplier	Incorrect constructed components and other quality problems caused by the external supplier
Damaged incoming material	Damages and scratches occurring on incoming components from the suppliers
Delayed incoming delivery	Late deliveries caused by internal or external suppliers, causing delayed order-start-up
Missing/inadequate documentation	The documentation from the R&D department is inadequate regarding instructions and drawing
Incorrect design	Incorrect design causing re-design
Incorrect incoming material	The material composition of the incoming components from the supplier is incorrect
Incorrect number of incoming material	Incorrect number of components from the storage
Damaged incoming material	Caused by internal or external supplier
Unnecessary meetings	Meeting not generating any actions or specific decisions taking time
Incorrect error-reporting	Incorrect reporting of deviations in the error-handling system
Assembly error	Problems caused by the manufacturing department and the employees themselves
Incorrect error-reporting	Incorrect specified error-report from the operator
Delays compared to original plan	Delays compared to the original time-schedule, due to delays in the manufacturing process
Change orders	A re-design of the product is required which requires a change order.
Non-compatible material	Materials with correct design that in reality are not compatible
Unplanned disruptions	Unplanned disruptions such as helping a colleague, unplanned operations or unplanned transport

4.5 Quantitative study from the error-handling system

In this section the five most reported problems from the cable-manufacturing department and the system-installation department are presented. The data was extracted from the error-handling system between January-2012 to April-2013, which gives a sufficient amount of data.

4.5.1 Quantitative study in the cable-manufacturing department

As can be seen in diagram 4.1, *missing data in documents/incorrect* is the most common problem for the cable-manufacturing department. Each problem is divided into what causes the problems; *own errors, external suppliers, other internal processe*s, *R&D* and *contract manufacturing*.

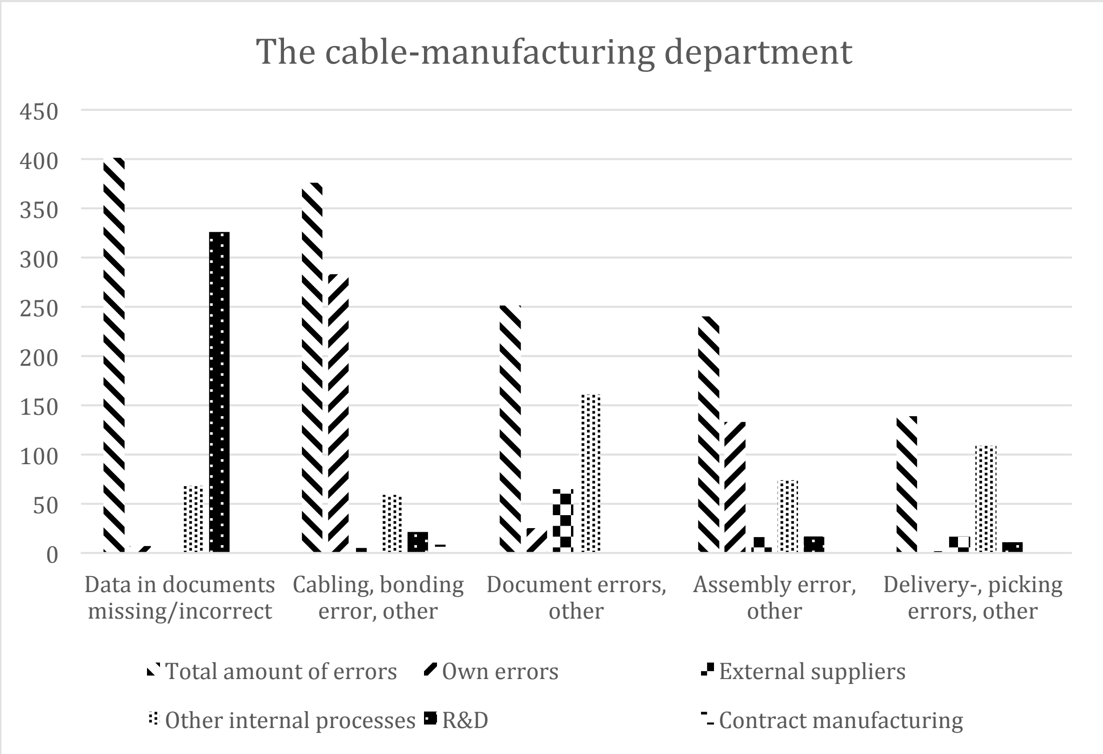

Diagram 4.1 – Reported problems in the cable-manufacturing department

For missing data in documents/incorrect from R&D caused the highest amount of the problems, see table 4.2.

4.2 - Most commonly reported problems in the error-handling for the cable-manufacturing department

	Total amount of errors	Own errors	External suppliers	Other internal processes	R&D	Contract manu-facturing
Missing data in documents /incorrect	**401**	7	0	68	326	0
Cabling, bonding error, other	**376**	283	5	59	21	8
Document errors, other	**251**	25	65	161	0	0
Assembly error, other	**240**	133	16	74	17	0
Delivery-, picking errors, other	**139**	2	17	109	11	0
Total amount of errors	**1407**	**450**	**103**	**471**	**375**	**8**

4.5.2 Quantitative study in the system-installation department

For the system-installation department, *delivery-, picking errors, other* is the most commonly reported problem, see diagram 4.2. For the problem, external suppliers causes the greatest amount, see table 4.3.

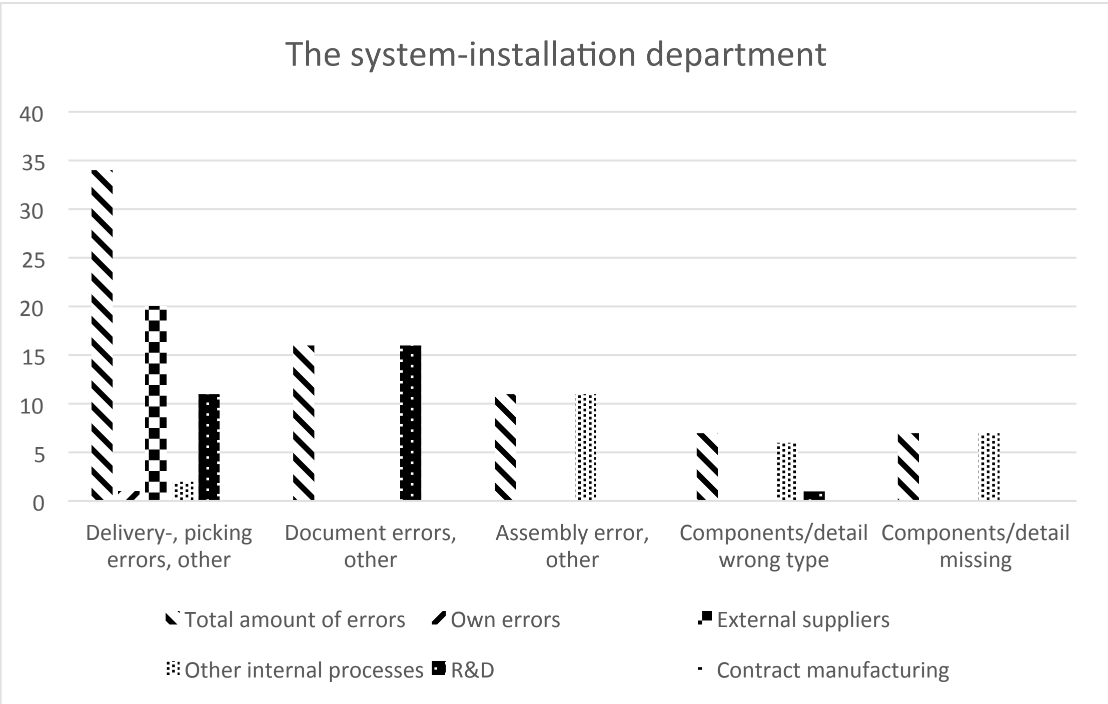

Diagram 4.2 – Reported problems in the system-installation department

The large difference between the amount of reported errors for the cable-manufacturing department and the system-installation department is due to that the system-installation department rarely error-report in the error-handling system.

Table 4.3 – Most commonly reported problems in the error-handling system for the system-installation department

	Total amount of errors	Own errors	External suppliers	Other internal processes	R&D	Contract manu-facturing
Delivery-, picking erros, other	**34**	1	20	2	11	0
Document errors, other	**16**	0	0	0	16	0
Assembly errors, other	**11**	0	0	11	0	0
Components/detail wrong type	**7**	0	0	6	1	0
Components/detail missing	**7**	0	0	7	0	0
Total amount of errors	**75**	**1**	**20**	**26**	**28**	**0**

5. Analysis

From the empirical findings it was concluded that problems discovered in one department was often followed by involvement of a chain of involved employees from different departments. In the current situation, this chain reaction is neither reported, nor considerate when evaluating projects and economical follow-ups. The involvement from different departments when a problem arise can be illustrated by one of the case examples provided in the empirical findings; incorrect screw from external supplier.

Case example: Incorrect screws from external supplier
One of the operator discovered that one of the screws did not fit in the cabling system. The operator contacted one of the production engineers to solve the problem. Neither the operator, nor the production engineer knew weather the problem was caused by a faulty design or by the external supplier, whereupon the R&D department was contacted. Two of the designers looked at the problem, concluding that the problem was caused by the external supplier. This process took approximately two weeks. Problems with external suppliers are handled by the purchasing department, whereupon the purchaser of the material was contacted. The purchaser did in turn contact the external suppliers, and the negotiation of having the supplier responsible for the problem took additionally four weeks. Meanwhile, the production planner was responsible for re-planning the manufacturing process; including put the operator in a new job and informing the sub-project planner that the manufacturing of the specific product was stopped.

The consequences arising from the exemplified problem are visualized in figure 5.1. Boxes marked in grey are activities outside of the manufacturing department, thereby not generating a cost for the manufacturing department. However, a total cost is generated for the case company.

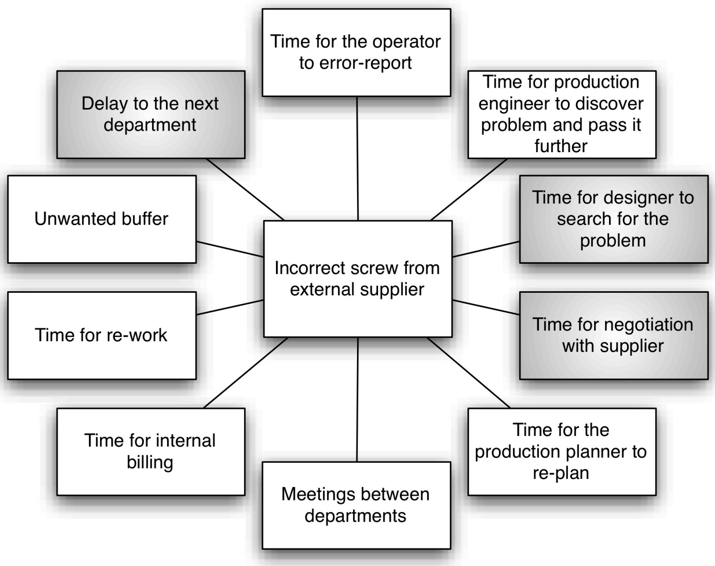

Figure 5.1 – Example of problem with incorrect screw from external supplier

In the specific case, the problem took six weeks to solve, excluding manufacturing and delivery time of the new product from the supplier, consequently this means six weeks stop in the production flow. Overall, six people were involved in solving the problem from three different departments.

5.1 Problem situation

Today, the project funds the entire order, deciding where to allocate resources. Since each department do not have any funding, the economy of each department is depending on internal billing of the previous sections in the company. This has resulted in each department acting as own individual businesses, completely depending on purchasing and selling components between departments.

Consequently, each problems that are to be solved in the company is connected to an order number, generating an internal supplier and an internal customer, namely one cost funder and one cost taker. Which department serving as a cost funder is most often discussed and decided in meetings, where each department represents their own business. Often, there is a conflict regarding who should bear the cost, which in turn lead to that problems are not solved. In the current situation, no department takes responsibility for their own mistakes, which consequently leads to an internal blame allocation chain. Marshall et. al., (1998) mean that this only increase the lack of understanding between the departments, which results in worsen communication and sub-optimization for the company as a whole.

It can be concluded from the empirical study that problems arising in the company are well understood from all departments, but there are dispersed opinions regarding where, how and who is responsible for the problem. The blame allocation has been found to lead to a circle of blame, where no one can identify the origin of the problem. In some cases, the personal contacts between employees fails, but in general it can be seen as a cultural issue of tension between departments which further causes an unwillingness to help each other. If the time would be allocated for actually solving the problem instead of discussing who should pay for it, problems could be solved much faster (Juran & De Feo, 2010).

Another problem is the fact that all products consist of a number of customized solutions. Many of the problems are not revised due to the belief of that the customer solution is unique, but in many cases it has turned out that what from the beginning was considered as a unique solutions are used in other projects. Parts of the manufacturing can be seen as prototype building, meaning that each individual product is expensive to manufacture.

Further, in the empirical findings it was found that the most common problems were caused by internal suppliers, external suppliers, by the manufacturing department itself or by other disruptions within the process. It can further be seen that each problem that causes a stop in the production flow generates a number of consequences for the company, see figure 5.2.

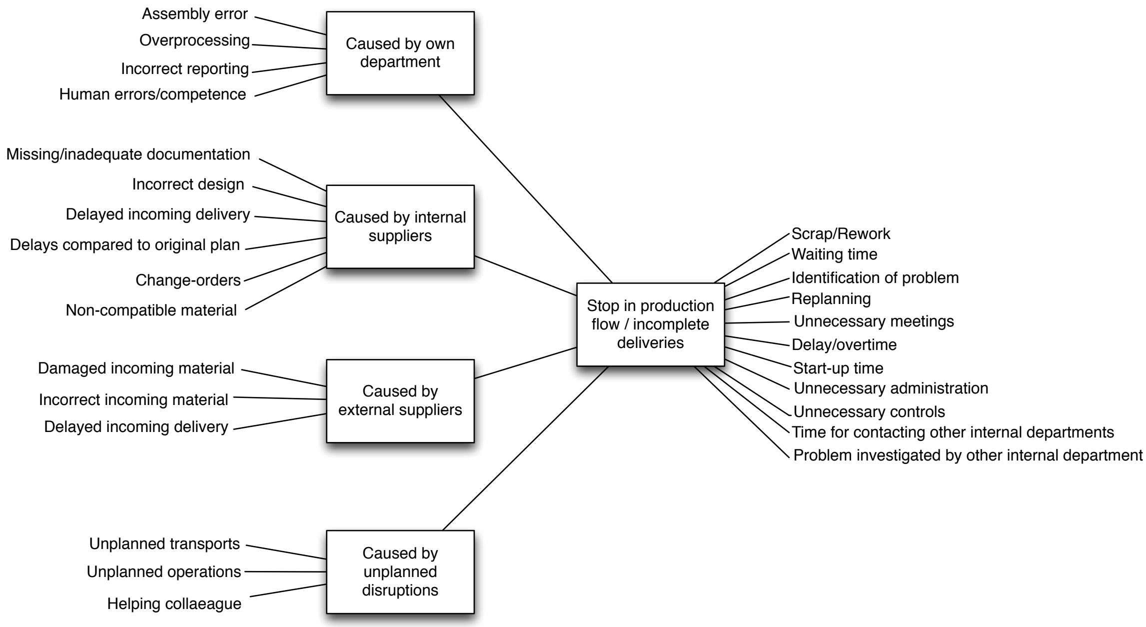

Figure 5.2 – Problems and consequences for the manufacturing department

The identified problems from the empirical study can be seen as underlying reasons to stops in the production flow. The consequences are effects arising in the manufacturing department, which are measureable and therefore quantifiable as a CoPQ. Consequentially, it is concluded that the identified problems does not cause any costs per se, but the consequence of the identified problem does.

5.2 Process examples

In order to identify a pattern of activities and people involved to a problem solving, generic processes for how a problem is solved have been identified. In order to measure and further monitor the consequences and thereby the CoPQ, generic models must be used.

From the empirical study it was found that the different manufacturing departments act in different ways when a problem arises. Further, not only the problem solving process differs, but also the culture regarding when and how the error reports are made. Since the company has a low-batch manufacturing process where each product is unique, many of the problems and the steps in the problem solving process are specific. Hence, it can be concluded that process-maps generic for the entire manufacturing department cannot be constructed.

Thus, process-mapping has been compiled for different processes in each department in order for the measurements to be credible. If a generic process-map would be compiled for all departments in the manufacturing function, the estimated values would differ from the reality so much that the value of such a model would be questionable.

5.2.1 Process examples for the cable-manufacturing department

In the cable-manufacturing department, four generic processes for solving problems has been identified; problems caused by the R&D department, problems with incoming material, delays from previous departments and problems caused by the cable-manufacturing department itself.

The first example occurs if a problem caused by the R&D department arises; either from missing/inadequate documentation or incorrect design, see figure 5.3. First, the product is set aside meanwhile the operator contacts the production engineer, who investigate the occurred problem, and error-report. Thereafter the process can take two paths, depending on if the product is released or active. If the product is released, problem will be discussed at the daily meeting where designers from the R&D look into the problem, coming up with a solution. If it is an active product, the process will look somewhat different. The production planner contacts the product planner, which in turn reports the problem to the sub-project manager. Thereafter, the sub-project manager contacts the R&D department in order to resolve the problem. Depending on the nature of the problem, the process can proceed in different ways. If the problem is considered simple it is often solved directly by the designer, but if the problem is considered more complex, an updating of documents or a re-design of the product is required.

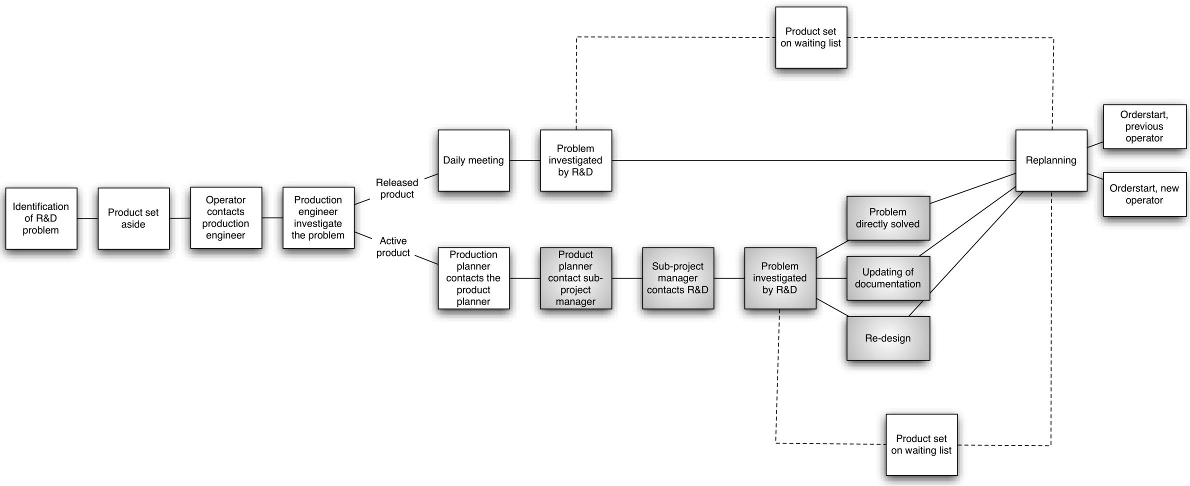

Figure 5.3 - Problem solving process when R&D causes a problem

If the problem is not critical for continued work the operator can continue to work on the product, but if it is a severe problem the product will be placed on a waiting list. Finally a re-planning of the manufacturing process is made, and the responsible operator is set in another job. If the stop is considered as prolonged, the operator is assigned a new cabling-system and the product is set on the waiting-list; otherwise the operator is assigned tasks such as cleaning or helping a colleague. When the problem is solved, the order can be continued. This can be performed by the original operator or by a new operator depending on the availability of the operator. It has been found that it takes longer time for a new operator to start up the job, due to that the new operator do not know what operations that have previously been done.

The second process example regards problems with incoming material, which can arise from either incorrect incoming material, errors caused by external suppliers, damaged incoming material or non-compatible material, see figure 5.4.

When the problem arises, the product is set aside and the production engineer or production planner is contacted. Thereafter, the production engineer or production planner contacts the storage, which are managing all problems concerning incoming material. If the problem is caused by the storage, such as incorrect picking, the employees check if material is available and thereafter send the material to the manufacturing department. If new material is not available, the storage contacts the purchasing department, which order new material. If an external supplier causes the problem, the storage directly passes the problem further to the purchasing department, which are responsible for contacting the supplier. If the delivery time from the external supplier is too long, the subproject manager can decide to let the engineering workshop fix the problem. When the material is received the order can start, and either the original or a new operator continues the job.

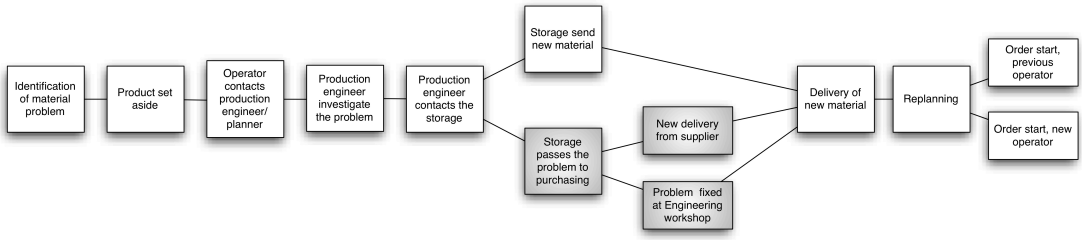

Figure 5.4 - Problem solving process for problems with incoming material

The third process example occurs when materials are delayed from internal or external suppliers before the order starts, see figure 5.5. In this case, the production planner discovers that the material for the order is not available in the storage, whereupon the material planner is contacted, which in turn contacts the responsible department. Meanwhile, the order can be either postponed or started. If the order is postponed, the material planner has to re-plan the production process while waiting for delivery of material. In cases when the missing material is not critical for the order to start, the order can be started with approval from the manager. In this case, the manager has to sign a form, stating the approval.

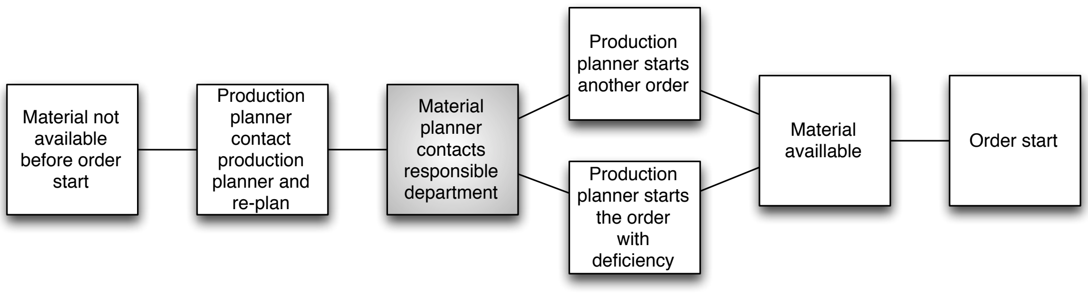

Figure 5.5 - Problem solving process when material is not available before order start

All of the three paths generate a certain waiting-time for the product. The total time from the order stop to order re-start is denoted as delay, which will affect the next department in the next department. Consequently, this will generate extra cost for the next department in terms of overtime. Further, in between the different steps the waiting time varies. To a large extent the product is standing still as no actions are taken at all. All problems causes administrative time in terms of internal billing and meetings deciding what instance should be responsible for the problem, and thereby the financier.

The last process example occurs from problems caused by the manufacturing department itself. Those problems can be discovered internally by the operator or the inspector, see figure 5.6. Further, the internal or external customer can detect a problem. When the problem is found, an error-report is made by the detecting instance. Most often, the operators in the manufacturing department can correct the problem by performing re-work. In cases when the operators do not know how to solve the problem the problem is passed to the production engineer, which in turn help the operator solving the problem or taking a decision of sending the product to the engineering workshop. In both cases, an inspection is performed to ensure that the problem has been corrected.

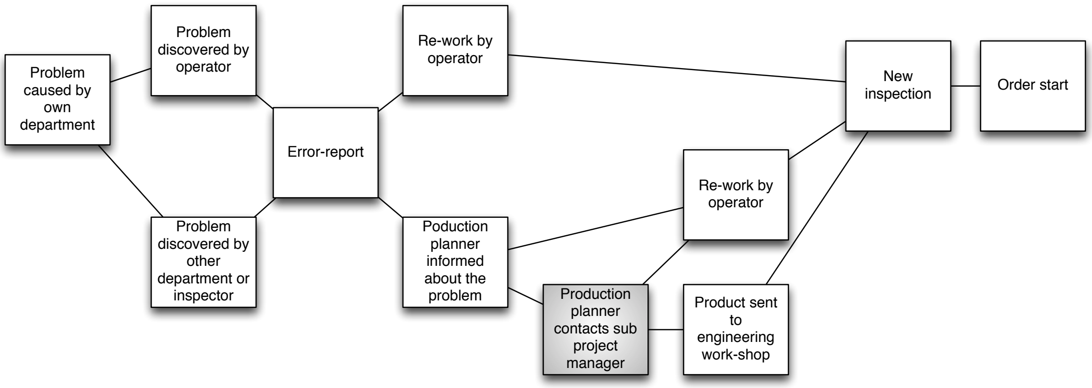

Figure 5.6 - Problem solving process for problems caused by own department

Problems regarding the error-report are often occurring; most often the detecting instance fail to error-report or the error-report is incorrect. If the error-report is defaulted, the economical follow-up will be unbalanced; due to that time for solving a problem is not reported. In this case, the production engineer has to make a follow-up including asking the operator what they have done the non-reported time. This in turn causes extra administrative job for the production engineer.

It is important to note that the complexity of the problem arise in ascending order regarding detecting instance; the later in the chain the more consequences (Krishnan, 2006). The operator often discovers a problem directly when it happens, and can correct it immediately. The inspector often find the problem in a later stage when the problem is sealed, causing de-assembling for correcting the problem.

If the internal customer detects the problem, in this case the system-testing department, the product has to be re-sent to the cable-manufacturing department for re-work. Further, this often results in that the product has to be de-assembled, re-worked and assembled again. Meanwhile, if the external customer detects the problem, it causes more extensive problem handling, since the product has to be sent back to the company or requires travelling consultancy.

As described in the process examples, many of the costs constitute from time for find or solve the problem and administrative costs. Further, another severe problem is the long lead-times for actually solving the problem, where it can be concluded that no action at all from the employees causes the long lead times. This is particularly evident in the generated lead-times during and in between steps in the problems solving process. If there is no prioritization of solving problems, the product will remain standing causing delay for the department later in the manufacturing chain. The delay causes in turn that either steps in the manufacturing chain are absent or that the last step in the chain have to work overtime. It has further been found that the stress causes the operators to make more mistakes, which in turn lead to more problems. Further, the payment for overtime is very costly. If skipping steps in the production chain compensates the lack of time, it is most common that testing is defaulted. This causes that problems are detected later in the production chain, or in worst case detected by the external customer. Porter and Rayner (1992) mean that the later in the chain it is discovered, the more costly it is to correct.

5.2.2 Process examples for the system-installation department

From the empirical findings, it was found that the system-installation department does not follow any standardized processes, neither regarding ways of working, problem solving or error-reporting. The problem solving process differs between operators, depending on the nature of the problem. Further, it was found that the system-installation department to a large extent do not error-report at all, which has been found from interviews with operators. The statement has further been confirmed in the data from the error-handling system, since a very limited numbers of errors are reported from this department during the past year. As the quote from the system-installation department, where ”an estimation is that 20 % of the errors are never reported” actually shows that the awareness of the extent of CoPQ is not acknowledged by the employees.

Since the problem solving processes do not follow any standardized ways, it is impossible to create generic process-maps for the system-installation department. In those cases where process examples cannot be generalized, it is important to measure specific cases in order to understand the extent of how much those cases can cost the company, and identify improvement areas by identifying the largest sources of CoPQ (Roden & Dale, 2000). Therefore, two case examples mentioned in the empirical findings will be shown.

The first case example provided in the empirical study, space planning, is presented below.

Case example: Space planning
Products that are assembles often need to be moved in order to make space for vehicles to be upgraded or serviced, which causes a disorder in the layout. When vehicles are moved, three people are involved; one drives, one delegates and one move tools and other things occupying the lane. This in turn causes disorder in the moved product, not only due to that operators gets occupies, but also due to that tools and components are dis-assembled.

Products that need to be moved due to lack of space are currently not reported by the company. It is in the current situation not considered to be a problem by the operators, but rather a part of the daily job. In order to report this as a problem is obviously required that the operators know that a problem has arisen. Since it not reported, no costs for this problem have ever been measured. The relocation of the products results in that three operators are interrupted from their regular work to move the product. When the problem is solved they have to start-up their regular work again. The start-up often requires time since it can be a problem to know where to re-start and what has been done. This often results in that the operator makes more simple mistakes and assembling errors.

It can be summarized that the problem of space planning result in that the production planner needs to manage the transport and that the operators needs to relocate the products. Further, it takes time for the operators to return to their original job and create order. This in turn causes a delay, compensated by overtime for the operators. The consequence of the problem is visualized in figure 5.7 below.

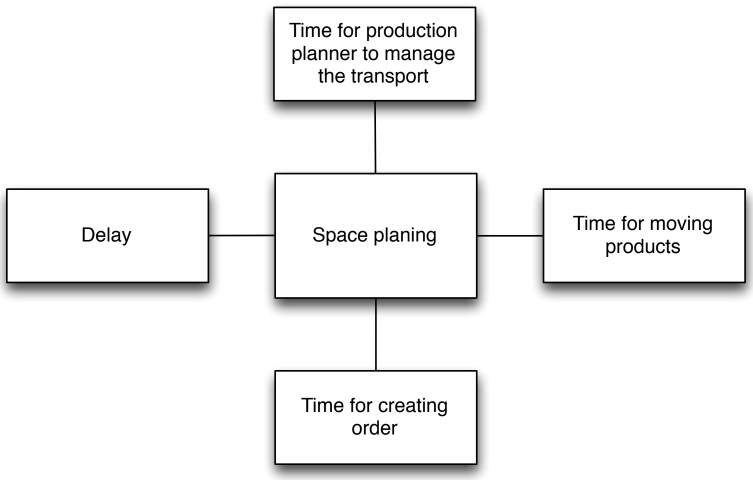

Figure 5.7 – Consequences of the case example; space planning

The second case example from the empirical study, updating of serial number list, is presented below.

Case example: Updating of serial number list
All final products includes a serial number list, containing all components included. This list is further supposed to be delivered to the final customer. During the process, a number of re-designs and upgradings cause changes of components, which should be updated in the serial number list. Before the delivery to the customer, this list is not always updated. In order to quickly fix the list, employees from the system-installation department and the system-testing department needs to get involved for fixing the list, which involves employees from both the system-installation department and the system-testing department.

The problem is discovered in the system-testing department, but involves operators from the system-installation department. Several operators are required to update the list, for components that has been changed from the original design during the process as a consequence of re-designs or design upgrading. The cost driver in this case is the time for discovering the replaced components. In addition, it takes time for updating the serial number list. Further, this causing a delay of the delivery to the external customer. In cases where the time to delivery to the external customer is tight, this might cause a delayed delivery to the customer, generating penalties. The consequence of the problem is visualized in figure 5.8 below.

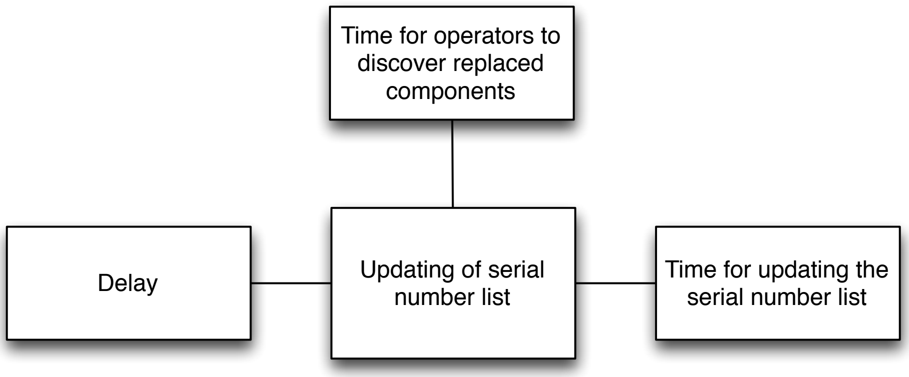

Figure 5.8 - Consequences of the case example; updating of serial number list

5.3 Development of a CoPQ-framework

It can be concluded that there is an uncertainty regarding the costs arising as a consequence of an identified problem. In order to measure this chain of costs a CoPQ-framework has been developed. This framework is based on problems found in the empirical study; both from the qualitative and quantitative study. The model is thus based on company specific characteristics.

5.3.1 Refined framework

It was found that the conceptual framework presented is not adequate in creating an understanding of the findings in the empirical study. Therefore, a reconceptualization of the theoretical framework was needed. The refinements were needed mainly due to that CoPQ areas were identified in the manufacturing not covered by current literature. Current literature does not take any consideration of the chain of activities and people involved arising from one problem, thereby the complexity of one problem is not established. Neither does current literature separate problems caused by internal or external suppliers or customers. If this separation is not made, the identification of improvements of internal processes cannot be made.

It was found in the empirical study that a problem leads to a sequence of events that can be traced by enacting a process-map or a value stream map (George et. al, 2005). So far, this has not been stressed in CoPQ theory. Further, when a problem occurs it involves several employees before the problem has been solved, which includes operator, production engineer and daily meetings. Thus, it can be seen that each problem follows a process, which is not reported by the company although generates a cost.

The goal of the refined framework is to measure CoPQ arising in-house and further incorporate those CoPQ with CoPQ from the external suppliers and customers. The framework will be a mix of the micro and macro PAF-model, which will be the base of the usage of the framework (Hwang & Aspinwall, 1996). Consequently, the framework is divided into the following categories; *appraisal losses, failure costs* and *invisible costs*. The failure costs are further divided into the subcategories; *internal failure costs, internal supplier costs, disruption costs, external supplier costs* and *external customer costs*, see the figure 5.9.

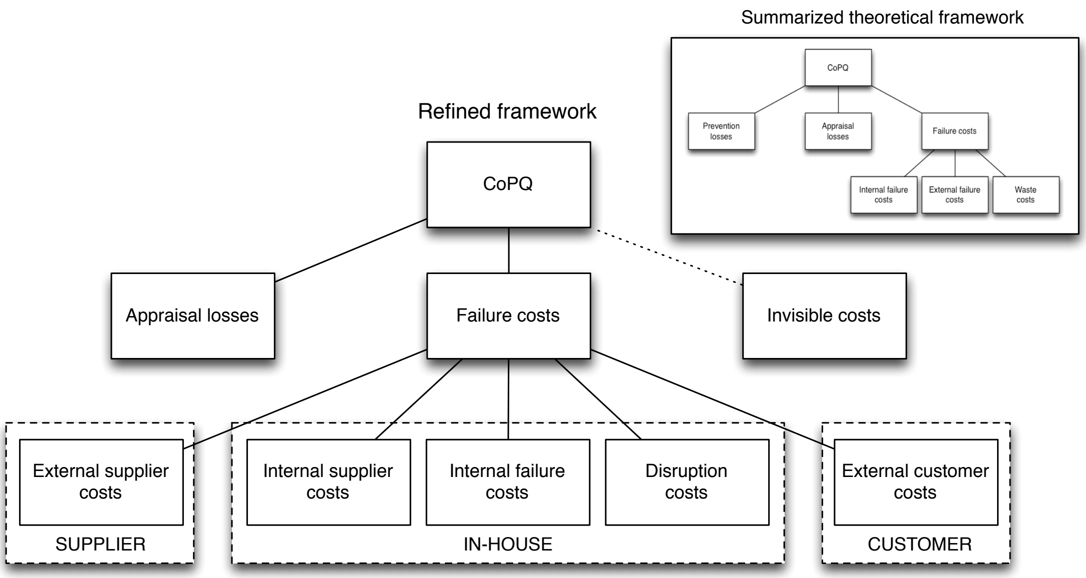

Figure 5.9 - Refined framework of CoPQ

Compared to the summarized theoretical framework, prevention losses have been removed in the refined framework. This despite the argument from Giakatis et. al. (2001), where prevention losses is seen as bad investments in prevention activities and should therefore be included. Instead it has been seen that prevention costs/losses are costs to improve the quality (Sörqvist, 2001) and should therefore be excluded. Juran and De Feo (2010) also exclude the prevention costs/losses but no explanation is further provided. Moreover, another reason to exclude prevention costs/losses is based on the statement from both Oakland (2003) and Porter and Rayner (1992), where companies have difficulties to know what should be included or excluded as prevention cost/losses. Therefore is it better to not include these costs and to risk measure incorrect prevention costs/losses making the measurement inaccurate. Today, the company does not measure this category and no such costs have been identified during the empirical study. Thus, it would be inappropriate to measure this, causing unreliable measurements, which stated by Dale and Plunkett (1991), can result in measurements with no accordance with CoPQ.

As can be seen in figure 5.9, the line is dashed for the invisible costs. This indicates that the category is not included in the model, but rather will be seen as an important category to consider but not to measure. If the invisible costs are excluded from the framework there is a risk of forgetting these problems and therefore management decisions can be incorrect or based on faulty assumptions (Krishnan, 2006). It was found in the empirical study that the case company does today not take any consideration of hidden CoPQ. Since, the invisible costs can be three to four times the visible cost (Gryna, 1999), this drains a large amount of costs not known by the company. Moreover, the invisible costs will not be measured based on definitions from both Feigenbaum (1991) and Gryna (1999), which indicates that invisible costs are costs that are hard to identify and measure, and are not quantifiable. However, at the time when a cost item has been identified or quantified the cost item will be seen as a visible cost and placed in an appropriate category, namely appraisal losses, external supplier costs, internal failure costs, internal supplier costs, disruption costs or external customer costs.

The category including appraisal losses is based on the theoretical framework, where appraisal losses are said to be profitless investments for quality (Giakatis et. al., 2001). In the cable-manufacturing department, many inspections are performed due to uncertainty of producing high-qualitative products. Further, the lack of trust between departments causes additional inspections. Some of these inspections can therefore be consider unnecessary since they would not have been performed if a product with the right quality had been manufactured. Consequently, these costs need to be measured.

The sub-categories of the failure costs are based on the original PAF-model (Feigenbaum, 1991). The subcategories have similarities with the subcategories of the theoretical framework, where internal failure costs and external failure costs are the same as described in the PAF-model, meaning problems caused by the department itself and caused at the customer (Gryna, 1999). The usage of these two subcategories have been strengthened by the findings which indicated that a large amount of the errors are internal errors caused by the departments itself, which the customers have identified after the products have been delivered. The errors detected by the customers are more severe and costly, not only in monetary terms but also in intangible costs, such as reputation (Harrington, 1987).

Moreover, internal and external supplier costs are new subcategories in the refined framework. The reason for including those costs is to make a distinction between internal and external suppliers. Internal suppliers are defined as department within the company in previous steps in the value-chain, whilst the external suppliers are external companies. By separating the internal suppliers and customers from the external, improvement potential in internal processes can be identified and measured.

The final subcategory, disruption costs, have strong connection to the waste costs mentioned in the theoretical framework, although, the disruption costs only includes unnecessary transports and motion. In the original waste costs all of the seven wastes according to the Lean Philosophy were included (Nicholas, 2010), but the other wastes; inventory, waiting time, over-processing and defects can appear in any sub-category in-house, i.e. internal supplier costs, internal failure costs or disruption costs.

In order to clearly visualize if costs arise within or outside the company, the subcategories are further separated depending on where in the value-chain they occur; namely into supplier, in-house and customer. This is inspired by Dale and Plunkett (1987), which use a value-chain approach to point at where efforts have to be done. Further, by identifying if the problem arises from the supplier, in-house or the customer, it is easier to identify improvement suggestions for internal or external processes. It is important to include both the internal and external factors, since it is equally important to satisfy the external customer as the internal (Sörqvist, 2001).

5.3.2 Connection between CoPQ and the refined framework

It has been stated that the consequences from an identified problem generates a cost, namely a CoPQ. Therefore, in order to find and measure CoPQ in the company, the problems causing the CoPQ first have to be identified.

In order to identify what problems generating CoPQ, the identified problems were connected to the refined framework, namely to two main categories; appraisal losses and failure costs. Obviously, costs cannot be connected to invisible costs, since those are not found. The identified problems can in turn generate one or several of the CoPQ, see figure 5.10.

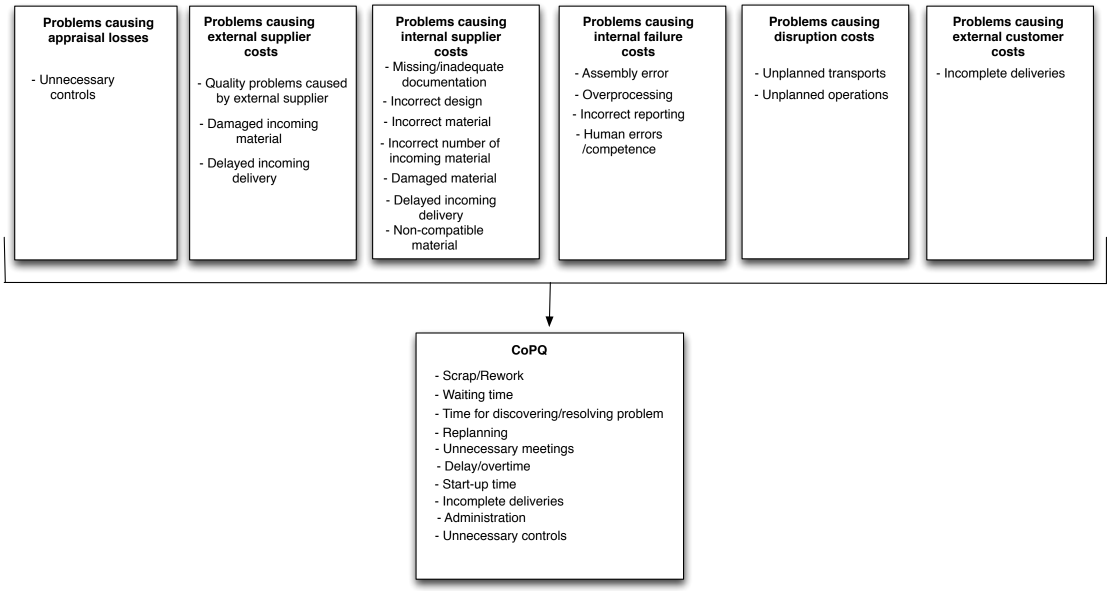

Figure 5.10 - Connection between CoPQ cost items and the refined framework

5.4 Quantification of CoPQ

In order to understand the consequences of poor quality, a quantification of CoPQ have been made by identifying costs in each step of the process examples. Only the generic processes will be quantified, thus for the cable-manufacturing department. Since no generic processed could be identified for the system-installation departments, calculations based on case examples will be provided.

In order to quantify the costs incurred in the problem solving process, an estimation of the average standard costs have been made. The quantification will be based on time estimations provided from interviews with involved people, multiplied with standard costs for each step provided from the finance department. All problems connected to a CoPQ are described in table 5.1. The costs connected to each step in the process examples are defined in appendix VII.

Table 5.1 - Explanation of CoPQ cost items

Problem	Explanation
Scrap/re-work	Cost for scrap and re-work an error causes, generating material cost and personnel cost.
Waiting-time	The time and costs when the product is set on the standing-still list, causing an unwanted inventory. Generates capital tied up in assets in terms of interest charge.
Identification of problem	Time taken for relevant personnel to find the problem and error-report. Generates personnel costs.
Re-planning	The time taken for re-planning an order when the order is stopped. Generates personnel costs.
Unnecessary meetings	Defined as meeting time for solving the problem between two or more employees from different departments, including daily meetings, planned meetings, unplanned meetings and MRB meetings. The time for unnecessary meetings generates personnel cost for each employee participating in the meeting.
Delay/overtime	Time for compensating for a delay, such as overtime. Generates personnel cost.
Start-up time	Time taken for the previous or a new operator to start a new job when an order is stopped, and to re-learn the job when problem is solved. Generates personnel costs.
Unnecessary administration	Administration costs, excluded from the other costs, to solve the problem. Generates personnel costs.
Unnecessary control	Cost for extra or unnecessary controls. Generates personnel cost.
Time for contacting other internal departments	Time taken for contacting other departments when trying to solve problem. Generates personnel costs
Problem investigated by other internal department	Time taken for relevant personnel from other internal departments to investigate and solve the problem Generates personnel costs.

5.5 Step-by step guide for process-based investigation of CoPQ

In order to identify, choose and measure CoPQ, a practical step-by step guide for identification of CoPQ has been developed, see figure 5.11. This will give the company an understandable method to evaluate and monitor the economics, effectiveness and efficiency of quality activities and to see how poor quality affects the company (Harrington, 1987).

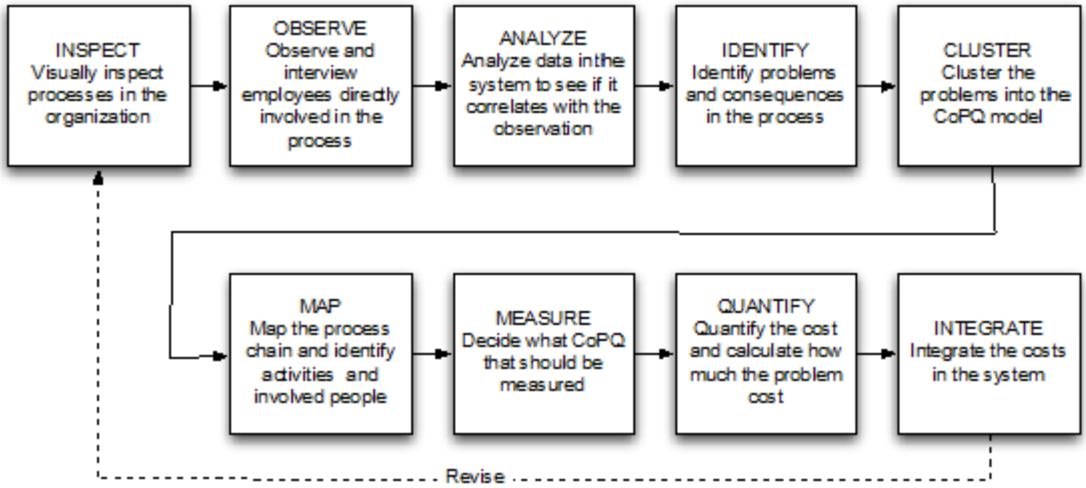

Figure 5.11 - Step-by-step guide for process-based investigation of CoPQ

First, the company has to visit and visually inspect the ways of working in the processes they want to perform the measurement. Thereafter, in order to identify problems, interviews and observations have to be conducted. It is important not to only look at the process that are to be measured, but also to get external perspectives in order to broad the view of the problem. Those perspectives can be found from interviewing employees from other departments, i.e. internal suppliers and customers. However, stated by Dale and Plunkett (1991), comparison can be made internally between departments, but external comparison should be avoided. When the information is collected from interviews and observations, it has to be analyzed and validated together with the data found in the error-handling system in order to see if the collected information is consistent with the system or if other not reported errors have been found.

Moreover, the problems and their causes in the process have to be identified through a problem/consequence analysis. In this analysis the company finds why the costs occur and what is causing them. Thereafter, the errors should be clustered into the appropriate category of the refined framework. By using the framework the company can identify where the costs arise and where efforts and resources have to be allocated (Sörqvist, 2001).

Each problem, from order stop until order start, needs to be mapped in order to find the chain of activities and involved people. This includes finding out which departments the problem effects and how many people involved. In order not to make it too complex, generic processes can be found which to a large extent can be similar for different problem. In other words, when it is possible to generalize it should be done.

When the problems have been identified and processes have been mapped, the problems need to be separated into common or specific problems. Common problems should be continuously measured and therefore integrated into the CoPQ-model, but specific problems needs to be validated from the company if they are common enough to include. Specific error can preferably be excluded for the company, in order to focus on the most important errors (Hwang and Aspinwall, 1996). Since many of the problems are company specific, each individual company should choose which costs to include or exclude from the model (Feigenbaum, 1991).

When the errors are clustered into a category, they need to be quantified, in order to be measureable (Sörqvist, 2001). Subsequently a model, preferably an excel-model, needs to be constructed where average standard costs are established for each cost post. After a model is constructed, the model should be integrated with the error-handling system of the company.

After the integration the company should continuously measure the CoPQ. However, due to changing environments, it is important to revise the model continuously in order to find new problems and further adjusting the average standard costs according to the current conditions of the company.

5.6 Cost calculations based on the CoPQ model

A calculation based on the average costs was made, which were connected to each step in the process examples in order to calculate the invisible costs within and between each step.

5.6.1 Cost calculations for the cable-manufacturing department

The costs calculations for the cable-manufacturing department were connected to the process examples; problems from the R&D department, problems with incoming material, problems caused by the department itself and problems when material is not available before order start. Further, costs arising after the order has been manufactured was calculated; meetings, follow-ups and internal billing. Since one meeting most often covers many problems, one meeting cannot be integrated in the calculation of one problem. The costs represented are the minimum cost generated for each problem, regardless of how the problem is solved, see table 5.2.

Table 5.2 - Costs for each problem

Identified problem	Type	Cost
Problem with R&D	Released product, no action	5896 SEK/problem
	Active product, no action	4500 SEK/problem
Problem with incoming material	Incorrect material from external supplier	6106 SEK/problem
	Incorrect picking from storage	8515 SEK/problem
Problem caused by own department	Problem found and corrected by operator	4248 SEK/problem
Problems before order-start	Start order with deficiency	831 SEK/problem
	Not start order with deficiency	602 SEK/order
After manufacturing	Meetings	4826 SEK/meeting
	Follow-up and internal billing	2477 SEK/day

It can be concluded that only the company currently reports only a small amount of the actual cost of a problem. In table 5.3, it is shown how many percentages of the total cost that is reported. The calculation shown is only examples for the percentage of the total cost of a problem that is in the current situation reported by the company.

Table 5.3 - Percentage of the costs of each problem reported by the case company

Example of reported problem	Percentage reported by the company
Incorrect incoming material, from external supplier	14,1 %
Incorrect incoming material, picking	19,7 %
Inadequate documentation from R&D, no action	20,4 %
Problem caused by own department, incorrect assembling	28,3%

It can be seen that the more people involved in the problem, the more inaccurate the report. For incorrect incoming material from external supplier, the company reports only 14,1 percent of the total costs. Problem caused by the manufacturing department itself, such as incorrect assembling, have the least involvement from other internal department and the company reports 28,3 percent of the costs for such problem. Problems before order-start, meetings, follow-ups and internal billing are not reported at all. Therefore, it can be stated that the model shows invisible costs not currently reported by the company, thus should be included as visual costs in the error-handling system.

In table 5.4, the cost for the five most commonly reported problems are calculated.

Table 5.4 - Cost for the five most commonly reported problems

Five most commonly reported problems	Total amount	Cost	Total cost
Missing data in documents /incorrect	401	5896	2364463
Cabling, bonding error, other	376	4248	1597398
Document errors, other	251	5896	1480001
Assembly error, other	240	4248	1019616
Delivery-, picking errors, other	139	5896	848734
Follow-up and internal billing (days)	310	2475	767808
Total cost			**8078020 SEK**

The total cost of the problems is approximately 8,1 million SEK. This number is represented as the minimum cost generated from each problems, thus the cost for the problems can be considered higher.

The numbers shown was generated from an excel model that was developed by the authors of this master thesis on behalf of the case company. Due to confidentiality from the case company, this model cannot be visualized in the report.

5.6.2 Cost calculations for the system-installation department

The case examples for the system-installation department can be seen as invisible costs, since they are identifiable but not quantifiable (Krishnan, 2006). Costs occurring in the case examples are personnel costs and start-up costs for the operators. Another cost to include when the assembly of the product stops is the time for catch up lost time, which results in that simple mistakes are made due to time pressure. An additional cost that should be included is the costs for the process of error reporting. It is important to note that additional costs might arise, since all costs arising might not have been discovered due to that the problem cannot be generalized. The case examples can rather act as starting points for improvements when it comes to standardization of processes (Roden & Dale, 2000). A calculation of the total cost arising from the first case example, space planning, is presented in table 5.4. The costs are based on the average time for solving the problem.

Table 5.5 - Cost evaluation for the case example; space planning

Case example: Space planning	
Time for production planner to re-plan	Personnel cost for the production planner
Time for moving the products	Personnel cost, operators (x3)
Time for creating order	Personnel cost, operators (x3)
Delay/overtime	Overtime, personnel cost, operators (x3)
Total cost: 4816 SEK	

Further, a calculation of the total cost arising from the second case example, updating of the serial number list, is presented in table 5.5.

Table 5.6 - Cost calculation for the case example; updating of serial number list

Case example: Updating of the serial number list	
Time for operators to discover replace components	Personnel cost, operators and system-testing (x5)
Time to update the serial number list	Personnel cost, production planner
Delay/overtime	Personnel cost, operators (x3)
Total cost: 5848 SEK	

5.7 Evaluation of the CoPQ framework

The purpose with the framework was to create a framework, specific enough to be beneficial for the cable-manufacturing department and system-installation department, but also as general as possible to be used by the whole production process. All problems found have not been able to be categorized into the framework, since they are too specific. Therefore, some of the problems have been clustered with similar problems while others have been omitted. Subsequently, not all costs will or can be measured. If all problems would be measured it would require too much resources for the company and make the model complex and probably inaccurate. Inaccurate measurements is unlikely to be used by the company (Campanella, 1990), and it is better to first use simpler measurements and later make it more complex (Sörqvist, 2001). Therefore, it is better to exclude uncertain costs and make the model simple to be used by the company.

Further, it is important to note that generic models cannot always be applied, due to changing environments. Therefore, it is important to continuously update and revise the generic models as well as the average standard costs.

Moreover, to some extent the employees do not error-report or report incorrect, which have been found during the empirical study. It is important to take this into consideration when measure CoPQ, since the data from the error-handling system is not completely reliable. Further, when the employees do not error-report, cause additional work for the production engineers. The incorrect or missing information in the error-handling system makes it difficult to know where improvements are needed or where to allocate resources for improvements.

The average standard costs are hard to estimate and quantify; however the company can easily revise these costs. It is important to note that the costs per se do not create any value to the measurements, instead it is the information received from the framework that is value adding. Therefore, the company should not put too large effort to estimate the costs but rather use the resources to reduce CoPQ.

Furthermore, the result from the test of the model shows that only a little amount of the costs are measured. However, it is important to know that some of the underlying average standard costs are roughly estimates and therefore the result is only an indication of how much the company misses to report and not an absolute term.

The use of the framework for the manufacturing department is a limitation since Sörqvist (1997) indicates that by only looking at one department can cause sub-optimizations. Therefore, it is important for the company to measure CoPQ in other departments in order to see if improvements in the manufacturing cause additional costs for these departments. Further, as stated by Harrington (1987) it is important to find problems early in the value-chain in order to minimize the costs. Therefore, the measurement should not only involve the manufacturing department, since it is in the end of the chain, but also previous departments, such as the R&D department and the purchasing department, to early find the problems and resolve it.

6. Discussion

The discussion is divided into three parts; theoretical implications, managerial implications and future research.

6.1 Theoretical implications

In current literature, it has been found that there is a lack of research regarding practices of how to measure and monitor CoPQ. This master thesis has shown a practical example of identification of CoPQ at a case company and further a step-by-step guide for practical implication for identification. This has been realized by interpreting a process-based investigation for identifying visible and invisible CoPQ in each step of a general process.

Further, from this master thesis it has been found that a problem causes a sequence of events, where the major costs can be associated to the process causing and solving the problem and only a small part to the specific problem. From previous research, the focus has been on creating a theoretical framework for categorizing cost items, but the underlying reasons of the problem are not further discussed (Harrington, 1987; Giakatis et. al. 2001; Dale & Plunkett, 1991). This master thesis contributes with the understanding of how identified problems have consequences that generates both visible and invisible costs. Further, it was found from the theoretical study that previous research focus more on the benefits of measuring CoPQ and which cost items to include in the different categories. For example Gryna (1999), Feigenbaum (1991) and Harrington (1987) motivate thoroughly the cost items to include in their theoretical frameworks, but do not cover the practical process of how to measure cost items in the first place. Consequently, it has been found that the literature is rather abstract and lacks information about practical use; specifically on how to identify, choose and measure CoPQ. Therefore, the authors of the master thesis have developed a step-by-step guide, see figure 5.11, in order to identify, choose and measure CoPQ.

The process describing the step-by-step guide to identify, choose and measure CoPQ and the process-based framework are considered to be the main contribution of this master thesis. Therefore, this master thesis has opened up for further research in this area.

6.2 Managerial implications

When measuring CoPQ, it has been shown that problems need to be generalized and classified in order to be manageable. Therefore, a process-based framework is proposed in order to find invisible costs in the process.

The model describing the practical steps will be seen as a guideline for the practical implication of the company. Since this master thesis only investigated and measured the costs for the manufacturing process, the company needs to perform this practical implication for the other departments in the company if CoPQ for the whole company are to be measured. By using the step-by-step guide the company has the knowledge of how to identify CoPQ, which will reduce the time and effort for investigating other departments.

It has been concluded that in order to monitor and control CoPQ in a company, it is important to start measure. Therefore, the company needs to start creating an awareness regarding what CoPQ actually are and how they affect the company. Hence, it is important to expand the horizon regarding the consequences in order to understand the chain of involved people and not only see the problem.

Since the environment is changing the framework needs to be continuously revised and adjusted to the prevailing environment and to identify new invisible costs or new incurred problems that need to be measured. Further, as the framework uses generalizations and average standard costs, the framework cannot be completely reliable. Consequently, the average standard costs need to be changed and updated as the processes of the company are improved. It is very important for the company that this is followed, since the measured CoPQ otherwise can be inaccurate. If the measurements are incorrect, it will point at areas of improvements that are not accurate and money will be invested in unnecessary activities.

It has been seen that the processes to solve problems are not standardized for the different departments. This makes the work with CoPQ time-demanding and complex. Consequently, the company needs to use standardized processes when solving problems. If the company would standardize their processes, the developed framework could be used in each department of the company, thus the complexity of monitoring CoPQ would decrease. Standardization of processes would further make the estimations and generalization more accurate, since the processes from different departments would look more similar and consequently not as rough estimates and generalizations need to be done.

To refine the model and find new ways to interpret costs, the operators should be more involved in the work with CoPQ. Since the operators have valuable input in improvements of daily activities, a forum for continuous improvements can be created where the operators can participate. Further it is important to communicate the importance of CoPQ and consequentially why it should be measured. By creating an understanding of the importance, the likelihood of correct reporting increase. The more thoroughly the reporting are made, the more reliable the measurements.

6.3 Future research

This research has emphasized to identify and monitor CoPQ by applying a process-based investigation of visible and invisible CoPQ, following the suggested step-by-step guide. The approach needs to be tested in other companies in order to see if the approach is feasible for a wider practical use. It would further be interesting to study how process-based investigation of CoPQ can be carried out in a company applying another manufacturing strategy, such as mass production, in order to see if this approach can be adopted for any type of manufacturing company regardless of manufacturing strategy.

Further, this research has delimited to only investigate the production processes of a manufacturing company. Thus, it would be interesting for further research to investigate if probes-based identification of CoPQ could be adopted in other departments of a company, such as R&D, HR and purchasing. It would further be interesting to investigate if process-based investigation would be suitable for non-manufacturing companies; therefore an interesting subject for future research would be to apply this in service companies.

Finally, as this research is delimited from any implementation strategies, it would be interesting to further investigate how to successfully implement a CoPQ measurement system.

7. Conclusions

The purpose of this master thesis is to develop a practical framework for continuously measuring and monitoring CoPQ in the production processes of a manufacturing company. It was found in the beginning of the thesis that not much emphasize was put on identifying CoPQ in the manufacturing department of the case company. It was further found that the costs reported today do not mirror the actual CoPQ as invisible costs are not being considered. Two research questions were guiding the way, each being addressed below.

How can CoPQ be categorized in a manufacturing company?

In order to control and monitor CoPQ, the costs have to be identified and put into a generic framework. The framework is based on a summary of the theoretical findings, in combination with the findings from the empirical study, see figure 5.9 below.

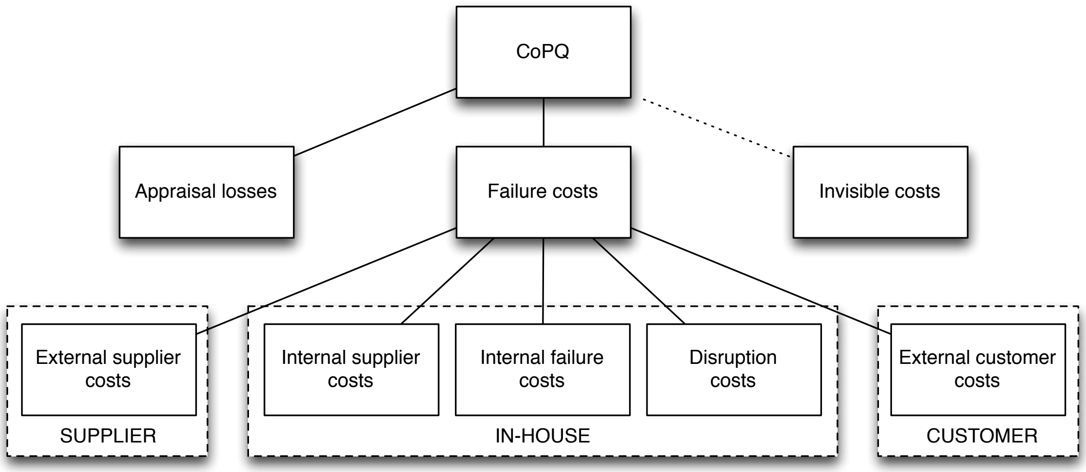

Figure 5.9 - Refined framework of CoPQ

The appraisal losses cover all costs for unnecessary controls, while the failure costs cover all costs caused by the supplier, in-house or the customer. The failure costs are further divided into external supplier costs, internal supplier costs, internal failure costs, disruption costs and final external customer costs. All of the sub-categories can be connected to the identified problems, but each of the problems can generate one or several CoPQ. A third category to take into consideration are invisible costs; costs that are not yet discovered. The invisible costs are not included in the measurements, but are important to take into consideration. If the invisible costs are excluded from the framework there is a risk of forgetting these problems and therefore management decisions can be incorrect or based on wrong assumptions.

How can CoPQ be identified?
From the empirical findings it was concluded that problems discovered in one department was often followed by a chain of involved employees from different departments being involved in the problem solving. It was therefore concluded that invisible costs were generated for each problem arising in the manufacturing department. Generic problems and costs were grouped into three main sources; problems caused by own department, problems caused by internal and external suppliers and caused by unplanned disruptions. Each problem can be identified as either a problem or as a consequence of the identified problem, where the consequences can be directly connected to a cost, in this case a CoPQ item. The identified problems can be caused by the department itself, by a supplier or by unplanned disruptions; in each case the problem causes a stop in the production flow. If a stop in the production flow occurs, this will in term cause a consequence connected to a cost, denoted as CoPQ. This is illustrated in figure 5.2 below.

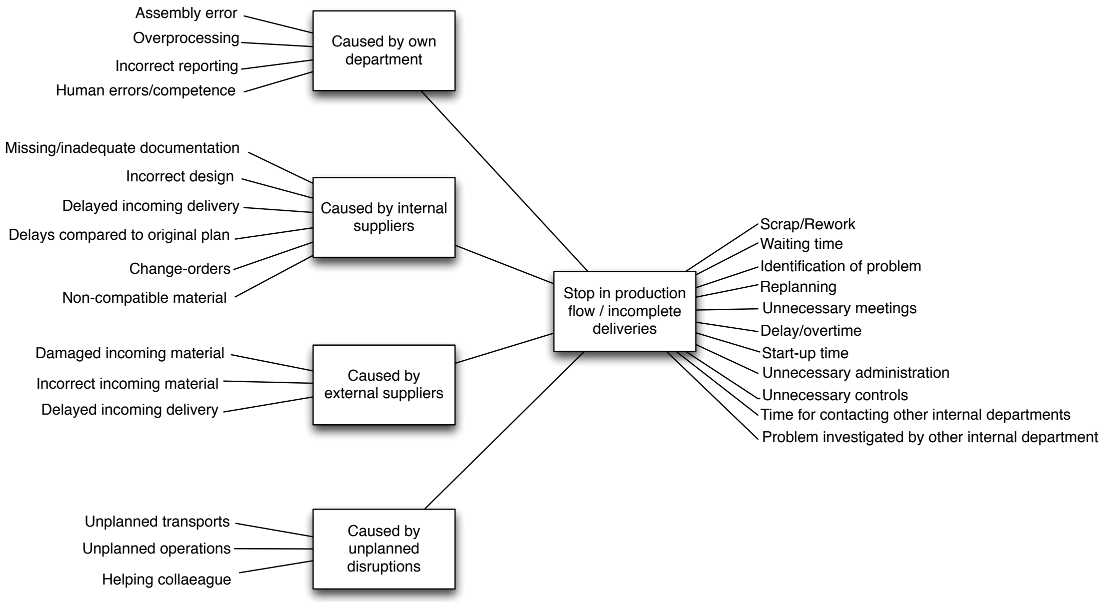

Figure 5.2 – Problems and consequences for the manufacturing department

It can be concluded that all identified problems do not create a cost per se, but the appearance of the identified problem will. Subsequently, problems need to be identified and followed in order for the cost to be eliminated. In order to identify a pattern of activities and people involved to a problem solving, generic processes for how a problem is solved have been identified. In order to measure and further monitor the consequences and thereby the CoPQ, generic models should be used. Thus, process-mapping has been compiled for different processes in each manufacturing department.

Since all products manufactured by the case company have customized solutions, each product will obtain a unique manufacturing process. Therefore, the manufacturing process at the company cannot be generalized for all products, nor can a generic process-map be obtained. It can therefore be concluded that completely generic process map cannot be developed for companies with a similar low- batch production containing customer-adapted solutions. In cases where process maps cannot be generalized, the company has to measure specific problems case by case.

In order to identify CoPQ in the manufacturing process hence apply the CoPQ model in a practical manner, a step-by step guide for identification of CoPQ has been developed, see figure 5.11.

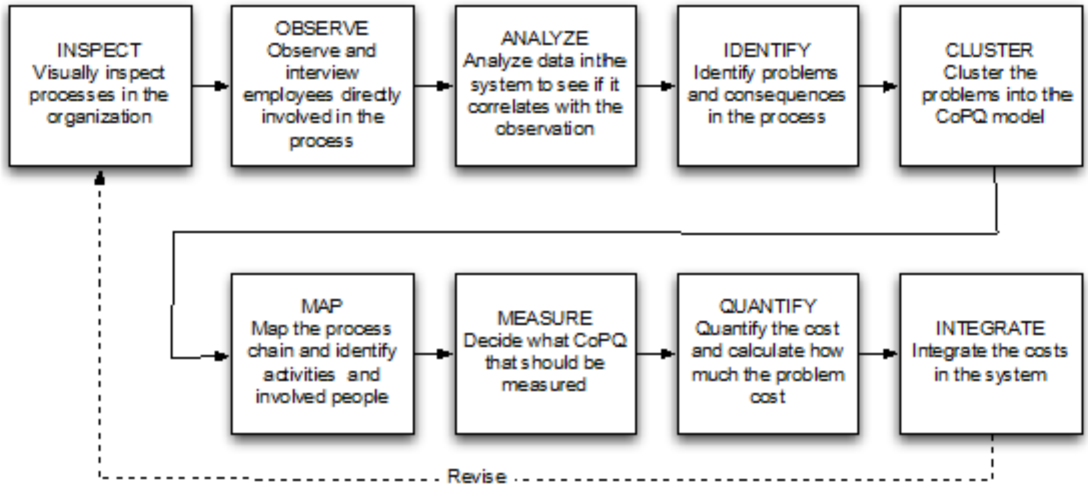

Figure 5.11 - Step-by-step guide for process-based investigation of CoPQ

By following those steps; CoPQ can be identified in the manufacturing process. However, due to changing environments it is important to continuously revise the model, in order to fit with the current conditions. Hence, the model can be refined and used over time as the company improves its processes.

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Appendix I - List of interviewees

Interviewees	Numbers of interviews
Inspector, cable-manufacturing	1
Inspector, cable-manufacturing	1
IT	1
Manager, incoming inspection and storage	1
Manager, cable-manufacturing	2
Manager, cable-manufacturing	1
Manager, engineering workshop	1
Manager, system-installation	1
Manager, system-test	2
Operator, cable-manufacturing	1
Operator, cable-manufacturing	1
Operator, cable-manufacturing	1
Operator, cable-manufacturing	1
Operator, system-installation	1
Operator, system-installation	1
Operator, system-installation	1
Process Manager	1
Purchaser	1
Product planner	1
Production engineer, cable-manufactuing	2
Production engineer, cable-manufacturing	1
Production engineer, system-installation	2
Production engineer, system-installation	2
Production Manager	1
Production planner, cable-manufacturing	1
Production planner, cable-manufacturing	2
Production planner, system-installation	1
Quality in supply	1
Quality in supply	1
R&D manager	1
R&D manager	1

Appendix II - Interview guides

Interview guide – manager for the cable-manufacturing department

Department structure

- How the department is structured?
- What processes does the product go through?
- Can the employees rotate between operations, or are they specialists?

Employees

- How are the operators trained/educated when employed?
- Rate of employee turnover?
- Rate of absence due to illness?
- How are people replaced due to absence?

Error-handling system

- How do the employees report?
- Who report and when?
- How much error causes a report?
- Do you consider that the reports are made in the right way?
- What do you consider being the biggest problem regarding the reports?
  - What are the consequences?
- How do you use the data from the error-handling system?
- How do you follow-up?

Input to the department

- What do you consider being the biggest problem regarding the inputs of material and design?
  - What are the causes?
- Do delays occur often?
  - Cause?
  - Effect?
- Are materials often missing?

In process

- What do you consider being the biggest problems in the processes?
- What causes re-planning or design changes/updates?
  - Cause?
  - Effect?
- How the re-planning is reported?

Output/control

- What are the most common errors in the output?
  - What are the consequences?
  - How are they solved?
- Where are control stations? How are they performed?
  - Frequency, place, time
- Who is responsible for control

Interview guide – production planners

- Describe your daily work
- What problems do you consider being the main problems
    - Cause?
    - Effect?
- How do you attack a problem?
- What authority do you have to re-plan?
- How many resources does it take to re-plan?
- What causes a re-plan? What triggers a re-plan?
- How do you prioritize between two products in the production? What authorities do you have?
- Do you use the results from the error-handling systems?
    - How?
    - How often?
- How do you report a re-plan?
- Are you responsible for the daily planning of the operators?
- How do you monitor the "standing still-list"?
-

Interview guide – production engineer in manufacturing

- Describe your daily work
- When do you enter the process?
- Describe a common problem and how you solve it?
- What problems do you consider being the main problems
    - Cause?
    - Effect?
- How do you attack a problem?
- What authority do you have to fix a problem?
- How is a problem reported to you?
- Do you use the results from the error-handling systems?
    - How?
    - How often?
- How do you monitor the "standing still-list"?
-

Interview guide – inspector in the cable-manufacturing department

- Describe your daily work
- When do you enter the process?
- Describe a common problem and how you solve it?
- What problems do you consider being the main problems
    - Cause?
    - Effect?
- How do you attack a problem?
- What authority do you have to fix a problem?
- How is a problem reported to you?
- How do you error-report?
    - How?
    - When?
- How do you proceed when discovering a problem?

Interview guide - operator in the cable-manufacturing department

- Describe your daily work
- What is your current position in the workshop today?
- How were you educated when first starting?
- What do you consider to be the biggest problem in your daily work?
  - How are the problems handled?
- How much work is standardized and how much is up to you?
- What do you do when a problem arise?
- How do you error-report?
- When do you error-report?
- Do you report when you start/stop a new job?
- If the documentation is inadequate, can you fix things from experience?
- How do you know your daily tasks?
- If someone is absent, can you replace them? Can someone else replace you?
- What do you consider about the workload?
- What causes re-planning or design changes/updates?
  - Cause?
  - Effect?
- Do you see any result from the error-reports
  - Are you informed of the results?
  - Are the same problems recurring?
- Do you work preventive to avoid problems from arising?
- Are there often new guidelines that make your daily work changing?
- How is the confidence for employees, both in horizontal and vertical direction?

Interview guide – R&D

- Describe the value-chain in the design process, from project start until it reaches the manufacturing department (specification, documentation, material, purchasing)
- How are documentation and checklists prepared? (documentation)
  - For the manufacturing department?
  - For the purchasing department? (tolerances and specifications for supplier, and number of components)
- How much of the design are modular-based? How much is new design?
- What are the biggest problems regarding new design?
- How does the employee turnover affect the project?
- How is knowledge created and captured?

- The project process
  - How is the project planned
  - Do you have enough resources? If not; what resource is most critical (time or money)
  - What would happen if the lead-time to the customer is expanded?

    - How the funding is organized?
- When is a project considered finished?

- Do you consider the product to always be finished when it reaches the manufacturing department?
- How are problems in the manufacturing department handled?
    - How are the conflict of interest between a new and old project prioritized?
    - How is an old project funded?
- What do you consider being the biggest problem in the interface between the R&D department and the manufacturing department?
- What do you consider being the biggest problem with the manufacturing department?
- What do you consider being the biggest bottleneck in the organization?

Interview guide – purchasing

- Describe your daily work
- When do you enter the process?
- Describe a common problem and how you solve it?
- What problems do you consider being the main problems
    - Cause?
    - Effect?
- How do you attack a problem?
- How is the time for your job reported when contacting the suppliers if errors occur?
- What do you consider being the biggest problem in the interface between the purchasing department and other department?
- What do you consider being the biggest problem with the manufacturing department?
- What do you consider being the biggest bottleneck in the organization?

Interview guide – material management

- Describe your daily work
- When do you enter the process?
- Describe a common problem and how you solve it?
- What problems do you consider being the main problems
    - Cause?
    - Effect?
- How do you attack a problem?
- What happens when a re-planning occurs?
- How do you communicate with storage, R&D and manufacturing?

Interview guide – incoming inspection and storage

- Describe the process
    - Arrival of goods
    - Incoming inspection
    - Delivery to head office (Picking components and frequency)

- How does the error-report process look like?
- What are the most common problems? Why do they occur?
- Do you often receive complained goods from the head office?
- Who do you contact when an error occur (manufacturing, purchasing, R&D)

Interview guide – system-test

- Describe your daily work
- When do you enter the process?
- Describe a common problem and how you solve it?
- What problems do you consider being the main problems
    - Cause?
    - Effect?
- How do you error report?

Interview guide– engineering workshop

- Describe what kind of jobs the department performance?
- What are the most common problems coming from the cable-manufacturing department and system-installation department?
- Who decides what jobs should be performed by your department?
- What is included in your responsibilities? Do you perform jobs outside of these responsibilities?
- How is the time for your job reported?
- How is the time for your job funded?

Appendix III – List of observations

Observed	Number of observations
Cable-manufacturing	2
System-installation	2
Incoming inspection and storage	1

Appendix IV - Invisible CoPQ
Invisible CoPQ according to Sörqvist (2001)

Traditional CoPQ	Arise from temporary problems affecting the business while those problems being continuously hidden.
Hidden CoPQ	Remaining costs, which are difficult to measure but are directly affect the business. To a large extent, the production costs are hidden as well due to lack of reporting
Lost income	Costs created due to not satisfying the needs of the external customers with the company's products and services, which the competitors can. These costs are hard to measure, and therefore require to be estimated
Customer's costs	Losses that affect external customers by reasons of poor quality in the supply chain. The customer's cost can be connected to costs of lost revenue and will create badwill for the company
Socio-economic costs	Losses in which affects the society because of the company's products and processes

Appendix V – Classification of CoPQ

CoPQ according to Feigenbaum (1991)

Prevention costs	• Quality planning • Process control • Design and development of quality information equipment • Quality training and work force development • Product-design verification • Systems development and management • Other prevention costs
Appraisal costs	• Tests and inspections of purchased materials • Laboratory-acceptance testing • Laboratory or other measurement services • Inspection • Testing • Checking labor • Setup for test or inspection • Test and inspection equipment and material and minor quality equipment • Quality audits • Outside endorsements • Maintenance and calibration of quality information test and inspection equipment • Product-engineering review and shipping release • Field testing
Internal failure costs	• Scrap • Re-work • Material-procurement costs • Factor contact engineering
External failure costs	• Complaints in warranty • Complaints out of warranty • Product service • Product liability • Product recall
Indirect and vendor CoPQ	• Extra unnecessary manufacturing operations • Unnecessary design features • Less labor • Less material • Less equipment • Rejected materials awaiting disposition • Overstocking of purchased material • Reduction in down time • Savings to customer through elimination of their incoming inspection afforded by the producer certifying product quality

	• Supplier's quality costs
Intangible and liability CoPQ	• Tarnishing of the company quality image • Liability exposure • Time of personnel involved with investigating the problem and preparing a case • Time of personnel to testify, attorney fees, expert witness fees, and other court costs
Equipment CoPQ	• Investment in quality information equipment • Equipment amortization • Installation • Occupied floor space
Life cycle CoPQ	• Service • Repairs • Replacement parts

CoPQ according to Harrington (1987)

Non-value adding costs	• Costs of effort that are not directly related to the product that the external customer wants
Equipment costs	• Costs to invest in equipment used for measuring, accepting or controlling a product (computers, typewriters, voltmeters, micrometers, coordinate measuring machines, automated test equipment. • The space the equipment occupies • Equipment used to print and report quality data
Customer incurred costs	• Loss of productivity while equipment is down • Travel costs and time spent to return defective merchandise • Overtime to make up production because equipment is down • Repair costs after the warranty period is over • Backup equipment needed when regular equipment fails
Customer dissatisfaction costs	• Customer-dissatisfaction in terms of lost revenue versus product quality level.
Loss of reputation	• Reflect the customer's attitude towards an organization rather than towards an individual product line. The costs cannot be imposed upon an individual product, but must be considered as having an effect of all product lines.
Lost opportunity costs	• The money a company forfeits when, because of poor judgment or poor output, the company fails to take advantage of an opportunity.

CoPQ according to Gryna (1999)

Failure to meet customer requirements and costs	• Scrap • Re-work • Loss of missing information • Failure analysis • Scrap and re-work – supplier • One hundred percent sorting inspection • Re-inspection, retest • Changing processes • Re-design of hardware • Re-design of software • Scrapping of obsolete product • Scrap in support operations • Re-work in internal support operations • Downgrading
Cost of inefficient processes	• Variability of product characteristics • Unplanned downtime of equipment • Inventory shrinkage • Variation of process characteristics from "best practice" • Non-value-added activities
Failure to meet customer requirements and needs	• Warranty charges • Complaint adjustment • Returned material • Allowances • Penalties due to poor quality • Re-work on support operations • Revenue losses in support operations
Lost opportunities for sales revenue	• Customer defections • New customers lost because of quality • New customers lost because of lack of capability to meet customer needs

CoPQ according to Dale and Plunkett (1987)

	Supplier/Subcontractor	*Company/In-house*	*Customer*
Prevention	Vendor assessment rating, and development Certification and accreditation Audits and site inspection Joint quality planning	Training Statistical process control Quality improvement teams Quality engineering Quality planning	Joint quality planning Field trials Market research Customer audits and inspections
Appraisal	Incoming inspection Sorting Organizing returns and replacements Inspections at supplier's site	Inspection and test Product testing Calibration Checking procedures	Product sign-off/certification Liaise with customer inspection activity
Internal failure	Work costs to point of scrapping Re-work costs Machining defective materials Lost production	Isolation of causes of failure Re-inspection Scarp and associated costs Re-work and associated costs	Discount on goods accepted on concession Downgraded goods sold cheaply
External failure	Costs attributable to but not recoverable from supplier Complaint handling Receipt and disposal of defective goods	Analysis and correlation of feedback data	Complaint handling Customer returns Free-of-charge replacements Field repairs

CoPQ according to Giakatis et. al. (2001)

Manufacturing loss	The decrease of the production equipment efficiency in order to decrease failures
Design loss	The money spent to achieve more than required product quality

Appendix VI – Problems in the different departments

Most common problems described by the cable-manufacturing department
Incorrect incoming material
Incorrect number of incoming components
Poor quality of incoming components
Delays from internal suppliers
Mis-designed drawings
Components and parts to be assembled are not compatible
Drawings and instructions are unclear from the R&D department
Disruptions and re-planning
Orders that should be error-free are not, which cause extra work
Products set aside occupies floor-space
Long lead-time for decisions and problem solving processes
Recurrent deviations and problems

Most common problems described by the system-installation department
Late delivery from internal suppliers
Late delivery from external suppliers
Late delivery of systems from the customers
Inadequate or missing documentation from the R&D department
Un-compatible components
Re-design and change-orders
Complex products and high amount of operations increase the risk of operations being forgotten caused by human factor
Lack of floor-space
Employees not involved in the assembling use or move tools or components, causing confusion
Systems to be repaired, upgraded or serviced are often have to be planned on short notice

Most common problems described by the R&D department
Cost and time estimations are always wrong
The project decides that the design is finished with a project even though they are not
Lack of documentation due to lack of time or that new designers do not know how to document
The operators do not have the competence to find out the problem
The operators in the manufacturing department cannot see the difference between a deviation and improvement suggestion
Storage/incoming inspection let through material with poor quality
The purchasing department cannot ensure that the quality standards are met due to low bargain power

Most common problems described by the purchasing department
Incorrect specification from the R&D department
Long lead times from the suppliers
Time pressure from the project plan causing “panic solutions”
Low bargain power towards external suppliers
Specifications set by the R&D department are hard for the suppliers to meet
Low compensation for downtime from external suppliers when a problem arise

Most common problems described by the material management department
Problems are not discovered in the incoming inspection and storage
Many re-planning due to quality problems
Incorrect purchased materials from the purchasing department
Incorrect design from the R&D department
Delays from external suppliers causing re-planning

Most common problems described by the incoming inspection and storage
Inadequate documentation regarding measurements and specification of requirements from the R&D department
Missing documentation from the R&D department
Fluctuations and re-planning from the material planners
Material planners initiate orders that is not required
Components that are sent back from the manufacturing departments have scratches and defects
Incoming material are not ordered in correct batches – components are missing
Reclamation of components having design problems
Long lead-times for response of e-mails from other departments when problems arise

Most common problems described by the system-testing department
Time and cost for trouble-shooting
Incorrect cabling and incorrect placed connectors from the cable-manufacturing department
Time pressure
Time and cost for fixing external problems caused by other departments

Most common problems described by the engineering workshop
Recurring problems
Problems cannot be registered, due to blame between departments

Appendix VII – Cost items from the process examples

Cost, own department	1	Problem discovered, error reporting	Personnel cost, operator
	2	Production engineer investigate the problem	Personnel cost, production engineer
	3	Daily meeting	Personnel cost, production engineer
			Personnel cost, designer
			Personnel cost, sub-project manager
			Personnel cost, method manager
			Personnel cost, meeting leader
	4	Problem investigated by R&D	Personnel cost, operator
			Personnel cost, production engineer
			Personnel cost, designer
	5	Re-planning	Personnel cost, production planner
	6	Order-start, previous operator	Personnel cost, operator
	7	Order-start, new operator	Personnel cost, operator
	8	Production planner contacts the product planner/sub-project manager/R&D	Personnel cost, production planner
	9	Production engineer contacts storage	Personnel cost, production planner
	10	Production planner investigate if the order is error-free	Personnel cost, production planner
	11	Start an order with deficiency	Administrative cost, manager
	12	Re-work	Personnel cost, operator
			Material cost
	13	New inspection	Personnel cost, inspector
Cost, waiting-time	14	Waiting-time, standing-still list	Capital tied up in assets
Cost, other internal departments	15	Incorrect picking	Administrative cost
			Picking
			Transportation cost
	16	Problem caused by external supplier	Administrative cost, storage
			Purchasing department contact the supplier
			Incoming inspection
			Picking
			Transportation cost
	17	Engineering workshop	Cost, engineering workshop
	18	Problem investigated by R&D	Personnel cost, designer
	19	Updating of documentation	Personnel cost, designer
	20	Re-design	Personnel cost, designer
Costs after order	21	MRB-meeting	Personnel cost, production engineer (pre-work)
			Personnel cost, production engineer
			Personnel cost, production manager
			Personnel cost, R&D manager
			Personnel cost, Quality manager
			Personnel cost, sub-project manager
			Personnel cost, production engineer
	22	Follow-up and internal billing	Personnel cost, production engineer