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Cost of Poor Quality
- Development of a tool for identification and quantification of CoPQ

Master of Science Thesis in Master Degree Program Quality and Operations Management

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Sandra Skogum   Louise Axelsson

Abstract

Companies aim to develop and produce high product or service quality to enable competitive advantage. During the 1950s, companies started to be interested in improving quality and quantifying quality-related problems. In these days, companies had the apprehension that high quality was equal to high cost while it was the opposite way that poor quality equals high costs. Therefore, the term *Cost of Poor Quality* (CoPQ) was started to be used, and can be defined as the total costs that could be eliminated if the processes or products of the company were perfect. It is often claimed that CoPQ represent 10-40 percent of a company's turnover, which shows the importance of identifying and quantifying CoPQ in the company. To visualize CoPQ and were these costs arise for top management, improvement actions could be based on facts and resources could be allocated to right place.

The purpose of the master thesis is to develop a tool for identification and quantification of CoPQ within the three functions Research and Development (R&D), Production and After Sale of a company. Further, the tool should present CoPQ in a visual way for an easy overview of the organization's current situation with regards to CoPQ.

In this master thesis, a qualitative research method has been used. Interviews with quality expert and specialists and a single case study have been conducted to gain detailed knowledge. Triangulation was used in order to increase validity and reliability of the results. The theoretical and empirical findings were analyzed and from that conclusions could be drawn.

From both theoretical and empirical findings, it was found that different companies have different views of CoPQ. It was concluded that one of the main core of working with CoPQ is to have a common understanding about what CoPQ is and what CoPQ should be used for in the company. It was concluded from the empirical findings that a tool, which identifies and quantifies CoPQ in a company's functions, would be preferable. The developed tool is designed in Microsoft Excel and consist of five parts; R&D, production, after sale, common CoPQ and soft factors. The tool aims to be used by two external investigators during two or three days. To facilitate the identification and quantification process of CoPQ a step-by-step guide was developed.

Table of Contents

List of Figures

1 Introduction

The introduction gives a background to the study and the chosen subject. Further it presents the context and purpose of the study, problem formulation and project limitations.

1.1 Background

Companies seek to develop, produce and provide competitive products or services that will meet and exceed customer needs, with a low cost and high quality (Bergman and Klefsjö, 2010). To be able to continuously improve quality, companies need to be aware of cost of poor quality that arise in the business operations as well as the resources needed to work on quality improvement (Oakland, 2003; Sörqvist, 1997). These costs started to be discussed during the 1950s when the interest to quantify quality-related problems and improve quality arose (Gryna, 1999). There are several terms describing these costs; Bergman and Klefsjö (2010) emphasize the usage of the term *Cost of Poor Quality* (CoPQ) since poor quality will result in higher costs. Harrington (1987, p. 3) confirms this by saying *"Poor quality costs your company money. Good quality saves your company money",* but decreasing CoPQ also involves changes of the quality mind-set throughout the organization (Harrington, 1987). Since CoPQ often is presented in money, Feigenbaum (1991) sees CoPQ as a financial common denominator, which can facilitates the communication between the upper management and quality department in order to make the decision-making more effectively. Sörqvist (1997, p. 51) defines CoPQ as *"the costs which would be eliminated if a company's products and processes in its business were perfect"*. This could also be explained as non-value adding costs. Sörqvist (1997) also expresses that one way to increase the company's profitability and competitive advantage is by reducing these non-value-adding cost. Organizations spend on average 10-40 % of their turnover on CoPQ, which is directly linked to profitability, and this high number often surprises the management team (Krishnan, 2006; Sörqvist, 1998).

CoPQ can be classified in different ways, and earlier research has developed different clusters to classify costs related to poor quality. One common classification, presented by Feigenbaum (1991), is the Prevention Appraisal Failure-model (PAF-model). He sorts the CoPQ into prevention, appraisal, internal and external failure costs. Whether prevention costs should be seen as quality losses, or not, is discussed by several authors (Giakatis et al., 2001; Juran and De Feo, 2010; Oakland, 2003). Giakatis et al. (2001) see prevention costs as investments, which will improve the quality and therefore exclude them in the term CoPQ. The same approach is the basis throughout the master thesis report. There are different interpretations of the general PAF-model, which facilitate the quality awareness within an organization (Juran and De Feo, 2010; Gryna, 1999; Harrington, 1999; Giakatis et al., 2001). However, since each organization is unique with individual requirements it is difficult to know how to measure CoPQ. Further, Krishnan (2006) uses the traditional metaphor "Cost of Quality Iceberg" to illustrate visible and hidden quality costs within an organization. It illustrates that the visible costs are more often taken into considerations while the hidden costs are not prioritized (Krishnan, 2006).

To be able to identify CoPQ, both visible and hidden, measurement is crucial (Krishnan, 2006). In early years, measurement of CoPQ mostly existed in manufacturing departments but during the 1990s organizations started to spread the knowledge of measuring CoPQ to other departments (Harrington, 1999). The majority of the identified CoPQ are visual costs since those are easier to measure than the hidden costs. According to Bergman and Klefsjö (2010) it is important to work towards high quality already in product development, since it is less costly to change a product's characteristics in early stage of a product value chain than it is in production or, even worse, on the market. Even though early research concludes that there is a need to spread the knowledge about CoPQ throughout the organization, there is no current classification of CoPQ with respect to the different functions. This shows the relevance to develop a tool that identifies and quantifies visible and hidden CoPQ and relates it to specific functions.

1.2 Context of study

The master thesis project is in collaboration between Chalmers University of Technology and a consultancy firm. The consultancy firm is a Swedish company located in Gothenburg and consists of a group of quality management specialists. They offer expertise in developing methods to improve their customers' organizations, competences, products and service competitiveness. Mostly, their work assignments concern five areas: proactive quality, reactive quality, operation management, after market and education/coaching. Independent of project type, the consultants intend to satisfy customers and adapt their expertise to meet customer needs and requirements.

In line with current literature, the consultancy firm experiences that today's companies are interested in CoPQ. However, the consultancy firm faces the challenges to identify and measure CoPQ within companies. Each consultant has its own way of calculating and estimating CoPQ and the firm emphasis the need of having a general tool to simplify this identification. This could increase the mutual understanding about CoPQ within the consultancy firm, and be valuable to their customers.

As part of the empirical study one manufacturing company was studied, with the size of a small and medium sized enterprise. The manufacturing company is a present customer of the consultancy firm, which makes this study interesting and valuable for both companies. The case company is a subcontractor of rubber and plastic products and located in the southwestern parts of Sweden. They supply 1400 customers worldwide within different industries and the largest customers belong to the automotive industry. Today, the company does not directly work with CoPQ, but they see the study as a chance to improve their quality work.

1.3 Purpose

The purpose of the master thesis is to develop a tool for identification and quantification of CoPQ within the three functions Research and Development (R&D), Production and After Sale of a company. Further, the tool should present CoPQ in a visual way for an easy overview of the organization's current situation with regards to CoPQ. The tool will be developed through a single case study and interviews with quality expert and specialists.

1.4 Limitations

The master thesis is limited to validate a tool, meaning the developed tool will not be implemented during the master thesis project. No actions regarding how to decrease CoPQ will be recommended. Furthermore, the tool will not investigate other functions besides R&D, production and after sale. The reason for the selection of these functions was to gain diverse understanding about where CoPQ exist in companies. Production is commonly investigated in order to find improvement areas in the production processes and after sale was interested to study to get information about customers' perceived product quality. Furthermore, R&D was chosen to study in order to see how actions in early product development projects affect CoPQ. However, the tool is considering input from other functions, see figure 1.1. Moreover, the tool is supposed to be applicable for small and medium sized enterprises, which manufactures products. This choice facilitates the ability to investigate the selected functions

R&D, production and after sale. During the case study one manufacturing process, the converting process, was investigated.

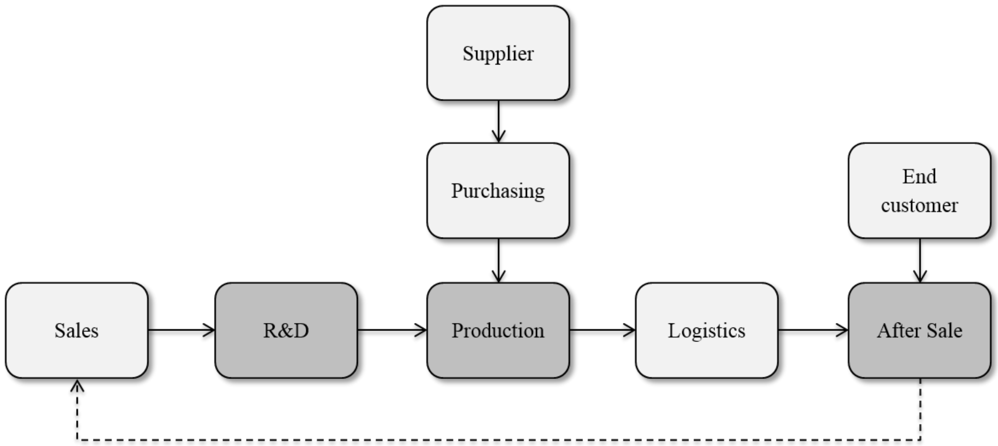

Figure 1.1 - The product's supply chain, highlighting the considered functions

The tool should be suitable for investigation of one company in a short period of time, preferably two or three days. No more than two investigators should be needed to perform the investigation. The outcomes from the tool will be a foundation of information to create short- and long term plans for quality improvement work.

2 Methodology

The chosen methodology for this master thesis is elaborated below. Research strategy, research design, research process and research quality are the sections described and discussed.

2.1 Research Strategy

Research strategy is a general orientation to conduct business research (Bryman and Bell, 2011). Remenyi et al. (1998) explain research strategy as the basic philosophical orientation of the research. According to Bryman and Bell (2011), research strategy includes two clusters, quantitative and qualitative research. Quantitative research is based on measurement, while qualitative research is not (Bryman and Bell, 2011). Creswell (2009) points out that the qualitative and quantitative approaches should be seen as different ends on a continuum, not as polar opposites.

Further, a deductive approach is often used in quantitative studies, while qualitative research follows an inductive approach (Barczak, 2015). Deduction is based on a logic, where conclusions are drawn through logical reasoning departing from theory (Ghauri and Grønhaug, 2010). Deductive theory is the most common view of relationship between theory and research (Bryman and Bell, 2011). The researcher, based on what is known, deduces a hypothesis (Bryman and Bell, 2011). According to Ghauri and Grønhaug (2010), the hypothesis will then be accepted or rejected. Induction means that general conclusions are drawn from empirical observation (Ghauri and Grønhaug, 2010). According to the authors, the process goes from observations to findings to theory building. Bryman and Bell (2011, p. 13) explains an inductive stance as: *"theory is the outcome of research"*.

According to Kirkeby (1994), deduction and induction alone are not able to support development of new qualitative knowledge. The author argues that deduction and induction do not evolve anything that is not already known. Abduction is an approach that expresses the possibility to evolve new knowledge (Kirkeby, 1994). Abduction is seen as an approach that refers to the process of studying facts and then devising a theory to explain them (Richardson and Kramer, 2006). Haig (2008) explains the term abduction as a form of reasoning. The reasoning involves both the generation and evaluation of hypothesis and theories. If a researcher would like to discover new things, other variables and other relationships, Dubois and Gadde (2002) suggest an abductive approach.

Dubois and Gadde (2002) introduce a new approach based on abductive logic called *systematic combining.* The authors (Dubois and Gadde, 2002, p. 554) explain the systematic approach as: ”*a process where theoretical framework, empirical fieldwork, and a case analysis evolve simultaneously, and it is particularly useful for development of new theories"*. Figure 2.1 visualizes that Dubois and Gadde (2002) enhance the importance of intertwined activities in a research process.

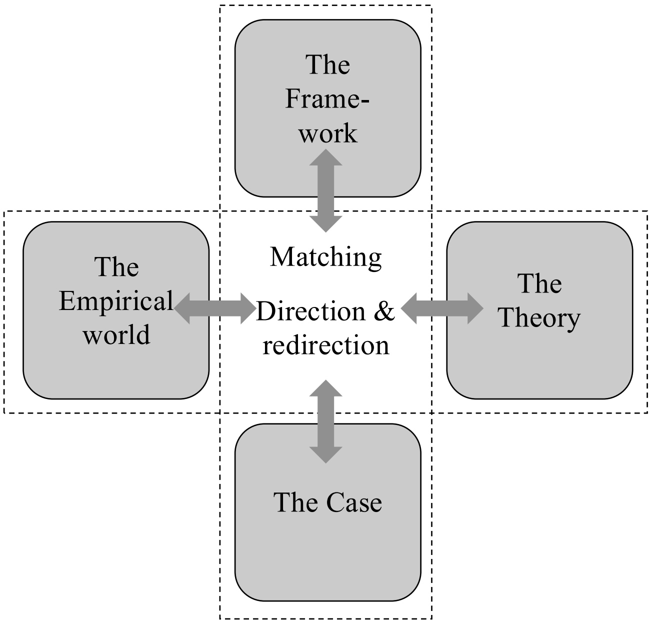

Figure 2.1 - The systematic combination approach, based on (Dubois and Gadde, 2002).

This master thesis follows a systematic combination approach. Theory studies and empirical research have been performed simultaneously. First, theory about CoPQ was studied to point out how to perform the empirical research. Secondly, the empirical research showed relevant literature to study. Further on, it was an ongoing process, where studies of theory and empirical research alternated.

2.2 Research Design

A further important decision to make is the choice of research design (Bryman and Bell, 2011). The authors explain research design as a framework for collection and analysis of data. Remenyi et al. (1998, p. 289) explain research design as: *"the plan that the researcher proposes to follow in the conduction of the research"*. Research design can also be described as the overall strategy, within the research, to get the information wanted (Ghauri and Grønhaug, 2010). Furthermore the authors point to the importance of differentiating research design and research method. Research methods are referred to as the techniques used to collect data (Ghauri and Grønhaug, 2010). Bryman and Bell (2011) examine five different research designs: *experimental design, cross-sectional design, longitudinal design, case study design* and *comparative design.*

Since the purpose of this master thesis was to develop a tool for identification and quantification of CoPQ, this master thesis follows a case study design, which is complemented by expert- and specialists interviews. A case study allows the researchers to get input from a company and also to practically verify the tool. The term case study research focuses on describing, understanding, predicting and/or controlling the individual (i.e. process, organization, group, industry, culture or nationality) (Woodside, 2010). According to Bryman and Bell (2011), a case study includes a detailed and intensive analysis of a single case. A single case is appropriate to use when the researcher want to test and establish a theory (Ghauri and Grønhaug, 2010). The main objective when conducting case studies is not always to increase knowledge (Runeson, 2012). The authors say that it may also bring change in the phenomenon that is studied.

Dubois and Gadde (2002) state that it is more a strength than a weakness to learn from one particular case. Furthermore, the authors explain that in-depth case studies are the best way to understand the interaction between a phenomenon and its context. One weakness discussed by Dubois and Gadde (2002) is the outcome from a case study. Case study research can tend to describe things well but the readers have to draw their own conclusions. The authors of this master thesis see a single case study as a strength, since it gives a deep understanding about the subject. However, the authors are aware of the weakness regarding just describing things without drawing conclusions. That is why the empirical study is complemented by interviews with quality experts and specialists. The interviews gave in-depth insight of which CoPQ parameters that are important to consider and how they can be quantified. Furthermore, the tool that has been developed is based on conclusions drawn from both the case study and the interviews.

2.3 Research Process

Defining the problem was the first step in the research process. The consultancy firm wanted a tool to identify and quantify CoPQ. One problem is that there is no tool available, that identifies and quantifies CoPQ, divided into different functions. Below, the research process steps are explained more in detail. The steps are: literature study, empirical study, data analysis. Activities included in the empirical study are: interviews with quality expert and specialists, two workshops and a single case study. The research process can be seen in figure 2.2.

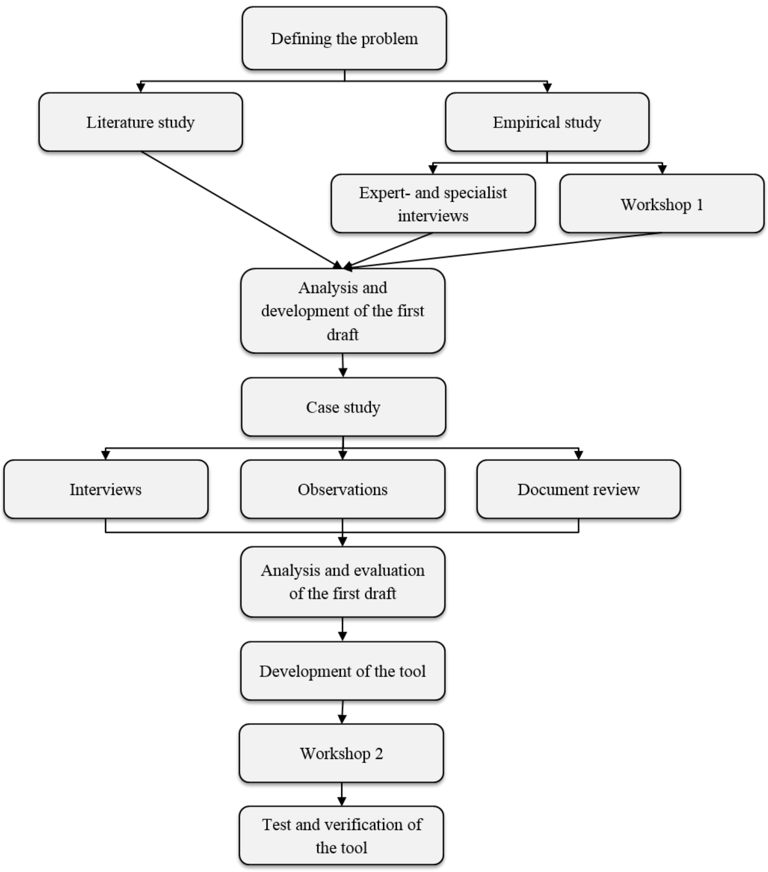

Figure 2.2 - The research process.

2.3.1 **Literature study**

After defining the problem, the process continued with a literature study. The research about CoPQ was mainly published more than fifteen years ago. Recently, research on non-value adding costs has focused on different aspects of Lean. That is why the theoretical framework was expanded with theory about Lean and Six Sigma. In the end of the literature study, the theory is summarized into a synthesis of CoPQ classification.

The purposes with literature reviews are many (Creswell, 2009); first, it gives the results from studies closely related to the research area. The existing theory also helps to establish the importance of the study. Further it gives the possibility to compare the result from prior findings (Creswell, 2009). Ghauri and Grønhaug (2010) state that a theory includes more than one concept, but also address how they are linked. With this argument this master thesis discusses many different authors' view of CoPQ. When performing literature studies, it is preferable to start with the most recent literature (Andersen and Gamdrup, 1994). Further, the author stated that the most recent literature is covering and gives advises to relevant, older literature. The authors of this master thesis started to study a broad view of quality, which then become more focused towards CoPQ.

According to Sörqvist (2013), the concept of Lean can be compared to CoPQ. The comparison can be done since both Lean and CoPQ identifies non-value added activities and resources (Sörqvist, 2013). Therefore, the literature study was complemented with literature about Lean. Moreover, literature about Six Sigma was added to the literature chapter. Six Sigma is a concept for improvements (Sörqvist, 2013) and was studied to increase the master thesis authors' knowledge about problem-solving tools. Keyword used during the literature study was: *Cost of Poor Quality, quality costs, internal and external customers, Lean* and *Six Sigma*. The literature used was found in the Chalmers library and in the search engine Summon. One frequently used database was Emerald Insight, which provided relevant journals.

2.3.2 **Empirical study**

Remenyi et al. (1998, p. 282) define an empirical method as *"any procedure employing controlled experience, observations, or experiments to map out the nature of reality or realities"*. The authors explain that an empiricist goes out and observe what is happening in the world by using experiments or passive observations. Conclusions can then be drawn by studying the observations and collecting related evidence (Remenyi et al., 1998).

Triangulation has been used in the research process of this master thesis. The definition of triangulation is, according to Yin (2014, p. 241), *"the convergence of data collected from different sources, to determine the consistency of a finding"*. Therefore, the empirical study of this master thesis was divided into several parts. First, interviews were done with quality expert and specialists. The interviews increased the master thesis authors' knowledge about CoPQ. Furthermore one workshop was held. The workshop focused on common cost parameters within three functions, R&D, production and after sale. Next step in the research process was a single case study within a company. In the case study, interviews as well as observations and reviews of documentation were included. The different parts will be explained more in detail below.

2.3.2.1 Interviews with quality expert- and specialists

Ghauri and Grønhaug (2010) state that interviews are often considered as the best method for collection of data. An interview situation is a process of communication, where an interviewee provides an interviewer with information (Andersen and Gamdrup, 1994). Ghauri and Grønhaug (2010) explain two different types of interviews, structured interviews and unstructured interviews. Furthermore, semi-structured interviews are an alternative that differs from the former ones. It differs in the way that following have been determined beforehand: the topics and issues to be covered, interviewees and interview questions (Ghauri and Grønhaug, 2010).

Semi-structured interviews have mainly been held during the research within this master thesis. Seven interviews were held with quality specialists working within the consultancy firm. Each of the interviews was conducted face-to-face during one to two hours. Three of the interviewees were specialists within R&D, two of them within production and the last two within after sale. The authors of this master thesis chose the interviewees together with the supervisors in the consultancy firm.

One expert interview was performed to further increase the knowledge within the quality field. This interview was of a semi-structured characteristic and was conducted over the phone. The choice of quality expert was done since the person has a long background within quality related questions. The expert has written books about CoPQ as well as Lean, and has a broad knowledge within these fields.

Andersen and Gamdrup (1994) states that people involved in an interview influence each other. The author argues that this is unavoidably, but the people involved can be aware of that and therefore decrease its effects (Andersen and Gamdrup, 1994). The authors of this master thesis were aware about this phenomenon and tried to ask questions that did not influence the interviewees in any direction. One example is the question: *Which CoPQ parameters are most critical?* The question is open and the interviewee had the possibility to decide upon which cost parameter he/she found most critical.

2.3.2.2 Workshops

The first workshop was held with 10 employees working in the consultancy firm. The workshop lasted during one hour and was arranged in the beginning of the master thesis project. A short presentation of the project was the first step in the workshop. Further, the group was divided into three smaller groups of three to four people. Each group had to focus on one function, R&D, production or after sale. The attending persons were assigned to a group where they had most knowledge. Each group got two questions to discuss and present, the questions are stated below:

Question 1: Which are the five most important CoPQ to identify in each function?

Question 2: Why are these cost parameters the most important?

The results from the workshop were used in combination with theory, interviews and case study to develop the tool.

One more workshop was performed when the tool was developed. This workshop aimed to discuss two cases about alternative ways to quantify CoPQ. The workshop was, like the previously one, held with 10 employees working in the consultancy firm. Further, the group was divided into two groups, where each group discussed one of the two cases. One case is stated below:

> **Case 1 - Rework**
>
> A company measures rework in production as "number of rework/week". The company has no idea about how time consuming a rework is. As a consultant, you think it is important to highlight these cost as you see it as CoPQ.
>
> How would you present the rework for the company, to enable them to relate rework to a cost?

2.3.2.3 Single case study including interviews, observations and documentation

By using the strategy of a case study, a researcher explores in depth a program, event, activity, process or individuals. A variety of data collection procedures are used over a sustained period of time (Creswell, 2009). Described by Ghauri and Grønhaug (2010), case study research in business studies is particularly useful when it is difficult to quantify the concept and variables under study. Therefore, one single case study was performed in a case company. In cooperation with the consultancy firm, the authors of this master thesis selected the case company. The company was suitable since the consultancy firm had already established contacts with the company. Further, the company is classified as a small to medium sized enterprise, which is in line with the limitations of this master thesis.

Yin (2014) stresses the need of many sources. The author says that no single source has a complete advantage over the others. A good case study should rely on as many sources as possible (Yin, 2014). The most commonly used sources of evidence in case studies are: documentation, archival records, interviews, direct observations, participant-observations and physical artifacts (Yin, 2014). The case study performed in this master thesis involved interviews, observations and documentation review. These activities are explained below.

Interviews

Yin (2014) argues that interviews are one of the most important sources when conducting a case study. Three types of case study interviews are explained by Yin (2014), prolonged interviews, shorter interviews and survey interviews. A prolonged interview can take place during at least two hours, in a single sitting or an extended period. Yin (2014) states that the more an interviewee acts in this manner, the more the person become an "informant" rather than a participant. Further, key informants are often important for a successful case study (Yin, 2014).

Shorter case study interviewees may be more focused and take around one hour (Yin, 2014). The interview questions may remain open-ended but the interviewer may follow the questions more closely (Yin, 2014). One purpose of this type of interviews is to confirm findings that the researcher already has established (Yin, 2014). The interviews that were done in this case study were mainly of the characteristic of a shorter interview and had semi-structured characteristic.

Structured questionnaires can be used in survey interviews in case studies (Yin, 2014). The authors of this master thesis did not use survey interviews in the first step of the case study. However, survey interviews were created and used when the tool was verified in the end of the master thesis project. The surveys were used to visualize soft factors that could not be quantified in money.

Observations

Observations are used to directly observe a social acting (Andersen and Gamdrup, 1994). Further the author states that the researcher is in direct contact with the things being observed, but the visual contact is minimal. Ghauri and Grønhaug (2010) describe observations as a tool, which allows listening and watching people's behavior. The findings can result in learning and analytical interpretations. Ghauri and Grønhaug (2010) state that the main advantage with observations is that first-hand information can be collected in a natural setting. One disadvantage is on the other hand that it is hard to translate the events into useful scientifically information.

Two different types of observations can be done, direct observations and participant-observations (Yin, 2014). This master thesis research used direct observations. According to Yin (2014), it is often useful to use observational evidence when providing additional information to the research. Further, to increase the reliability of the observational evidence, it is beneficial to have more than one observer making the observation.

Observations were done in this master thesis project in order to understand the case company's structure and processes. The observations made it possible to map the production process and also to increase the authors' knowledge about potential CoPQ parameters within the case company.

Documentation

Documentation can take many forms (Yin, 2014). For case study research, Yin (2014) states that documents are important to use in order to corroborate findings from other sources. Remenyi et al. (1998) states that documents can provide specific details, which can support the verbal accounts of informants.

For this master thesis, different documents were available in the case company. Process maps and organization chart were reviewed. These were compared to the observations done by the authors of this master thesis. Moreover, documents about CoPQ were reviewed. The documentation increased the knowledge of what measurements that already exist in the company and how high CoPQ are.

2.3.3 **Data analysis**

According to Creswell (2009) the analyze phase of data can include several components. The author further states that the analysis process involves making sense of text and data. Since mostly qualitative data have been gathered during this master thesis project, the focus of this analysis chapter will be on qualitative analysis.

Qualitative data derived from interviews and participant observations, are often unstructured textual material (Bryman and Bell, 2003). The authors state that these types of data are not straight-forward to analyze. Bryman and Bell (2003) explore three approaches for qualitative data analysis: analytical induction, grounded theory and narrative analysis. Further, the authors state coding as the key process in grounded theory. Coding entails reviewing transcripts and giving names to parts of potential theoretical significance (Bryman and Bell, 2003).

Ghauri and Grønhaug (2010) explain the advices from Miles and Huberman's book "Expanded sourcebook – A qualitative Data Analysis". The authors make a distinction between three components in analysis of qualitative data. These components are data reduction, data display and conclusion drawing/verification. In the data reduction phase, categories and themes are generated and identified by the researcher (Ghauri and Grønhaug, 2010). The authors of this master thesis found coding and data reduction similar each other. From now on, this step will be called coding in this master thesis.

The first step in the analyze phase was to compare and combine the findings from the literature study and the workshop. From this step, it was possible to design an interview guide. The second step was to compare the findings from the expert- and specialist interviews with the findings from theory and workshop. The findings were divided into one or more of the three functions, R&D, production and after sale. Coding was the fourth step in the analyze phase. Findings from literature study, workshop and interviews were coded in respectively function. The coding resulted into clusters. Each cluster included one or more cost parameters. From the coding session, a first draft about the tool's content was designed.

The case study resulted in more qualitative data. The analysis of the findings from the case study were also coded and clustered. The findings were either clustered into existing clusters from the first draft or into new clusters. After this analysis session, the second draft were developed. A second workshop was held in order to discuss two cases, which the authors of this master thesis found difficult to relate to costs. Two quality specialists from the consultant firm participated in smaller meetings to discuss how the findings from the tool could be presented. The quality specialists had knowledge about different methods to use in order to present CoPQ.

Furthermore, the tool was applied in the case company. This step was done in order to validate the use of the tool. The authors of this master thesis used the tool as it intends to be used during two days. This step evolved the researchers to get an understanding about the usefulness of the tool as well as what could be changed to further improve the tool.

2.4 Research Quality

Bryman and Bell (2003) state three criteria for evaluation of business and management research. The criteria are reliability, replication and validity. These will be explained more in detail below.

2.4.1 Reliability

Research reliability refers to whether the findings and measurement are consistent and stable (Remenyi et al., 1998). According to Bryman and Bell (2003), reliability refers to whether the results are repeatable. Remenyi et al. (1998), state that reliability is especially important if the findings are intended to be used in other situations than the original. By doing interviews with people who work in different branches and different functions has ensured the reliability of this master thesis. In addition, a single case study has been performed to further increase the reliability. The two authors of this master thesis have attended all the interviews and the whole case study, which has ensured the reliability throughout the master thesis project.

To further increase the trustworthiness, the authors of the master thesis, had continuous contact with a quality specialist employed at the consultancy firm. The informant had knowledge about the case company but was not employed by the case company. Therefore the informant had the knowledge to verify the result found in the case company.

2.4.2 Replication

According to Bryman and Bell (2003), replication is similar to reliability. Further, the authors state that researchers need to spell out their procedures carefully to make replication possible. Therefore, the authors of this master thesis have described their research process in detail. The interview guides that have been used during the interviews can be found in appendix I, to further increase the potential of replication.

2.4.3 Validity

Remenyi et al. (1998, p. 291) define validity as *"The degree to which what is observed or measured is the same as what was purported to be observed or measured"*. Both Yin (2014) and Remenyi et al. (1998) discuss three types of validity; construct validity, internal validity and external validity. Construct validity can be explained as to what extent an operationalization measures the concept, which was supposed to be measured (Ghauri and Grønhaug, 2010). The authors state that construct validity is important if the research findings will be meaningful and interpretable.

Internal validity refers to the compliance between the content of the nominal definition and the operational definition (Andersen and Gamdrup, 1994). To ensure internal validity, information and data have been critical viewed. Triangulation has been a key aspect and therefore a literature study, interviews with quality expert and specialists and a case study have been performed. Furthermore, the interviews have been done with different people working in different functions and branches.

Ghauri and Grønhaug (2010) explain external validity as the extent, to what the research findings can be generalized, *to* as well as *across* persons, settings and times. According to Remenyi et al. (1998), external validity is whether the findings are generalizable to a wider universe beyond the immediate research environment. Yin (2014) states that case studies are generalizable to theoretical propositions and not to populations or universes. The goal when performing case study research is to expand and generalize theories and not to extrapolate probabilities (Yin, 2014). In this master thesis, the intention was to design a tool that is applicable in many branches.

3 Theoretical Framework

Quality management focuses on understanding the customer needs and the perception of the delivered quality (Alänge, 1994). Quality and different types of customers will be discussed in the introduction to this theoretical framework. Furthermore, the following chapter introduces the term Cost of Poor Quality (CoPQ). CoPQ has been explained by several authors, which is why this chapter describe and compare different authors view of CoPQ. Lean and Six Sigma are two contemporary management approaches discussed, and related to CoPQ, in the end of this chapter.

3.1 Quality Management

The following chapter introduces definitions of quality and the relation between quality and profitability is discussed. Since quality is strongly connected to customer satisfaction, two types of customers are described, internal and external customers.

3.1.1 Definition of quality

Quality has a wide range of definitions and meanings. One reason could be that people refer to it in different contexts (Sörqvist, 2001). According to Juran and De Feo (2010), it is crucial to have an agreement on a definition of quality throughout an organization to be able to manage quality. According to Juran and De Feo (2010) the definition of quality has been changing over the years. A popular definition was *"fitness for use"* and was mostly applicable in manufacturing industries but was not enough for service industries (Juran and De Feo, 2010, p. 5). Crosby (1992, p. 27) also defined quality from a producer perspective as *"conformance to requirements"*. However, the perspective changed to become more customer-oriented and Juran and De Feo (2010, p. 5) updated their definition to *"fitness for purpose"*, where it refers to that each product or service has to satisfy customer requirements and be delivered without failures. Bergman and Klefsjö (2010, p. 23) define quality with an expanded view as *"a product's or service's ability to satisfy, or preferably exceed, the needs and expectations of the customers"*. Instead of focusing on fulfilling customer needs the goal must be on exceeding customer expectations. This master thesis defines quality in the same way as Bergman and Klefsjö (2010, p. 23). Two common denominators of the definitions are according Sörqvist (2001) customer satisfaction and perceived quality. Customer's perceived quality is related to customer expectations, company's image and customer judgment. Here it is important to consider both internal and external customers.

3.1.2 Quality and profitability

Previously, many companies believed that high quality resulted in high costs but reality shows the opposite way, good quality will decrease costs (Harrington, 1987). In 1970s and 1980s companies systematically started to meet customer needs by working with quality improvement, which resulted in increased market share and profitability (Bergman and Klefsjö, 2010). In addition, Sörqvist (2001) means that high quality also results in increased productivity and customer demand for the company's products or services. To reach growth in profitability there are three ways to proceed, either through increased revenue, reduced costs or decreased capital tied up in assets (Sörqvist, 2001). However, improved quality will contribute towards profitability growth in all these three factors. Feigenbaum (1991) is confirming this when he states that no company will be profitable with a poor quality product. Further, Harrington (1987) discusses the relationship between quality and profitability saying that in order to increase profitability it is more effective to focus on improving quality rather than increasing sales. The reason to this is, when only focusing on increasing sales, it requires expanded resource capacity of staff, material, equipment, support personnel, managers etc. and the profit will not be enough in order to meet the expanded resources.

3.1.3 Internal and external customers

Dean and Bowen (1994) describe three different principles that characterize quality management. The first and most important principle is customer focus (Dean and Bowen, 1994). According to the authors, customer satisfaction is the most important requirement for long-term organizational success. Bergman and Klefsjö (2010) stress that customer satisfaction is related to the needs and expectations of the customer. The satisfaction requires the entire organization's focus to be on the needs of the customers (Dean and Bowen, 1994). Chang and Kelly (1994) point out that customer satisfaction does not only apply to the end user of an organization's products or services. It also applies to how people in an organization work together (Chang and Kelly, 1994). According to Juran and De Feo (2010), the term *customer* may refer to just a single person or an entire organization.

Juran and De Feo (2010) consider two primary groups of customers: the external customer and the internal customer, see figure 3.1. The external customers are defined as *"those outside the producing organization"* and the internal customers are defined as *"those inside the producing organization"* (Juran and De Feo, 2010, p. 96). Marshall et al. (1998) explain that much research has been focused on the service requirements of external customers. In contrast, a number of authors have asserted that internal service quality is the least understood but most important concept (Marshall et al., 1998). Further, Sörqvist (2001) states that satisfied internal customers are correlated with increased motivation and job satisfaction among employees.

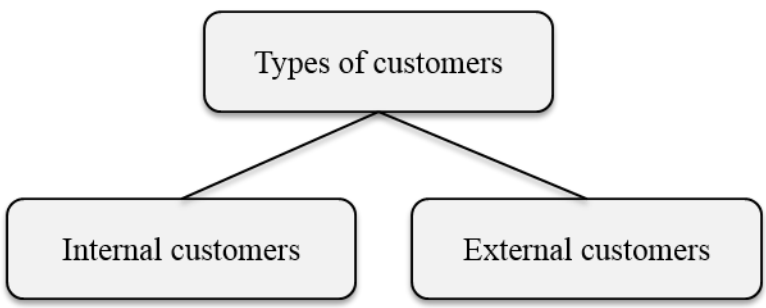

Figure 3.1 - Internal and external customers.

According to Juran and De Feo (2010) everyone in an organization plays three different roles: supplier, processor and customer. These roles are stated as internal customers, each of them receives something from someone, do something with it, and then pass it to a third individual (Juran and De Feo, 2010). Further, Juran and De Feo (2010) mean that the external customers may be impacted by the effectiveness in meeting the internal customer's needs. The literature shows the importance of satisfying both internal and external customers (Juran and De Feo, 2010; Marshall et al. 1998).

3.2 Cost of Poor Quality

Quality can be divided into two terms: potential quality and actual quality (Pyzdek, 2003). The potential quality is representing the maximum possible value that can be added from each input while the actual quality is the present value that is added from an input. According to Pyzdek (2003) the difference between those two aspects is waste. The waste will contribute to decreased profit in the company. CoPQ can also contribute to decreased profit and is unwanted in a company. In the following chapter the term CoPQ will be elaborated on.

3.2.1 **Introduction to Cost of Poor Quality**

Companies seek to develop and produce products or services that will meet and exceed customer needs, with a low cost and high quality (Bergman and Klefsjö, 2010). To be able to continuously improve quality, companies need to be aware of costs due to poor quality and resources needed to work on quality improvement (Oakland, 2003; Sörqvist, 1997). These costs started to be discussed during the 1950s when the interest to quantify and improve quality arose (Gryna, 1999). At this time Juran introduced the term *Quality Cost* but lately the term *Cost of Poor Quality* (CoPQ) became widely accepted and used (Sörqvist, 2001). One reason for the shift in terms is the increased understanding of what actually is costly for the company, which is poor quality of product, service or process (Sörqvist, 2001). This is also confirmed by Bergman and Klefsjö (2010), who emphasize the usage of the term CoPQ since poor quality will result in higher costs. It is estimated that organizations spend on average 10-40 % of turnover on quality costs, and this high number often surprises the top management team (Krishnan, 2006; Sörqvist, 1998). The total quality cost includes costs that occur when investing in prevention activities, conforming product or service requirements and costs associated with failures to meet requirements (Pyzdek, 2003).

Juran and De Feo (2010, p. 75) define CoPQ as *"the costs that would disappear in the organization if all failures were removed from a product, service, or process"*, which also can be explained as non-value adding costs (Sörqvist, 1997). Sörqvist (1997) also expresses that one way to increase the company's profitability and competitive advantage is by reducing CoPQ. It is stated by Harrington (1987, p. 3) *"Poor quality costs your company money. Good quality saves your company money"*, but decreasing CoPQ also involves changes of the quality mindset throughout the organization (Harrington, 1987). Foster and Whittle (1990) explain one challenge with changing the quality mindset. The challenge is to shift the focus of change from manipulation of structures and systems to seeing the world from the customer's perspective, and also to meet customer requirements by implementing programs.

Poor quality can be tough to describe in an understandable way but occurs when a product or a service does not succeed to meet all customer needs (Sörqvist, 2001). As already mentioned, a company needs to consider both internal and external customer needs which make the process of identifying customer requirements even more complicated but not less important (Sörqvist, 2001). To be able to improve product quality, motivate staff to make improvements and base decisions on facts, it is essential with measurements of CoPQ (Sörqvist, 1997).

3.2.2 **Visible and hidden Cost of Poor Quality**

If lacking measurements a company may never know whether they are doing the right things right, or the wrong things efficiently (Krishnan, 2006). This is why Krishnan (2006) stretches the importance of studying ideas of how to eliminate all types of failures and potential failures within an organization. It is known that a large part of both internal and external failure costs are invisible. Since the total quality costs typically are between 10-40 percent of a company's turnover, these costs are known as the *hidden factory* or *the golden mine* (Krishnan, 2006). Organizations have to identify all hidden costs and eliminate them if they contribute to poor quality (Krishnan, 2006). The author continues to argue that these hidden costs can only be captured through a cost of quality measurement system.

According to Krishnan (2006) the hidden costs can be enormous, sometimes between three and ten times the visible costs. Nevertheless, many decisions are only based on information on visible costs (Krishnan, 2006). Both the visible and the hidden costs can be illustrated by the "Cost of quality iceberg", see figure 3.2. As seen in the figure, the visible costs are only the tip of the iceberg, while the remaining costs are less visible. Krishnan (2006) continues to discuss that many of the hidden costs go unrecognized because they are not measured or reported.

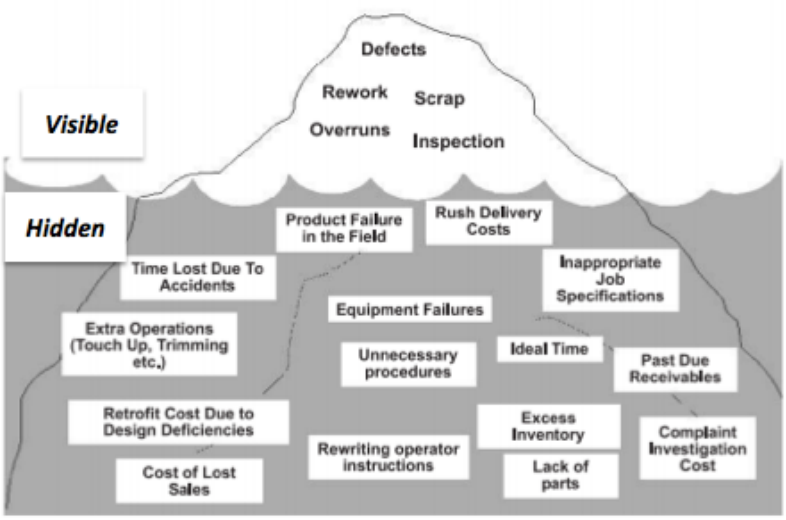

Figure 3.2 - The "Cost of quality iceberg", based on (Krishnan, 2006).

Sörqvist (2001) describes CoPQ as an iceberg as well, see figure 3.3. The main difference from Krishnan (2006) is that Sörqvist (2001) divides CoPQ into five categories; traditional CoPQ, hidden CoPQ, lost income, customer's costs and socio-economic costs. Sörqvist (2001) explains the reason for the categorization with the degree of difficulty to measure CoPQ. The traditional CoPQ is the tip of Sörqvist's (2001) iceberg, while the remaining categories make up the hidden costs.

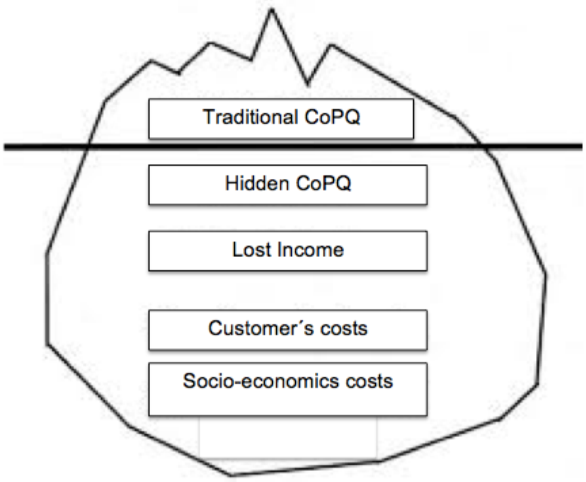

Figure 3.3 - CoPQ described as an iceberg, based on (Sörqvist, 2001).

Dahlgaard et al. (1998) discuss the classification of CoPQ by introducing a classification that includes visible and invisible costs. Aligned with Krishnan (2006), this classification also emphasizes the importance of visible and hidden costs and its relation to internal and external quality costs.

3.2.3 **Classification of Cost of Poor Quality**

CoPQ has been discussed by several authors. Feigenbaum (1991) was the first person to classify quality costs into a model called PAF, representing prevention, appraisal and failure costs. Tsai (1998) states that the PAF-model has been almost universally accepted for relating quality to costs. Since then, several authors have classified CoPQ in different ways. The following authors' classifications will be explained closer; Feigenbaum (1991), Juran (2010), Harrington (1999), Gryna (1999) and Giakatis et al. (2001). These authors' classifications were chosen, due to their width of time perspective, from 1991 to 2010. Furthermore, the different classifications have different views of CoPQ. The classifications are frequently used in the literature, which also make them relevant to present. A sample of cost parameters from the literature can be seen in appendix II.

3.2.3.1 Classification of Cost of Poor Quality according to Feigenbaum

According to Feigenbaum (1991) there exists coherence between product and service cost, and product and service quality. Good product or service quality is about meeting and exceeding customer needs, and it is the customer who decides the perceived quality. Further this also means that quality, that do not satisfy the customer, corresponds with not full utilization of resources. Unsatisfactory quality means unsatisfactory resource utilization, since the resources will not be optimal utilized when the product or service quality does not meet customer needs. This includes all quality cost generated throughout the total life cycle of a product or a service (Feigenbaum, 1991).

In companies, quality-related costs are divided into two parts; cost of control and cost of failure (Feigenbaum, 1991). Cost of control is cost needed to confirm the product or service quality, while cost of failure includes costs that are caused when the quality requirements of the product are not being met. Feigenbaum (1991) continues to classify the cost parameters into categories according to the PAF-model, see figure 3.4.

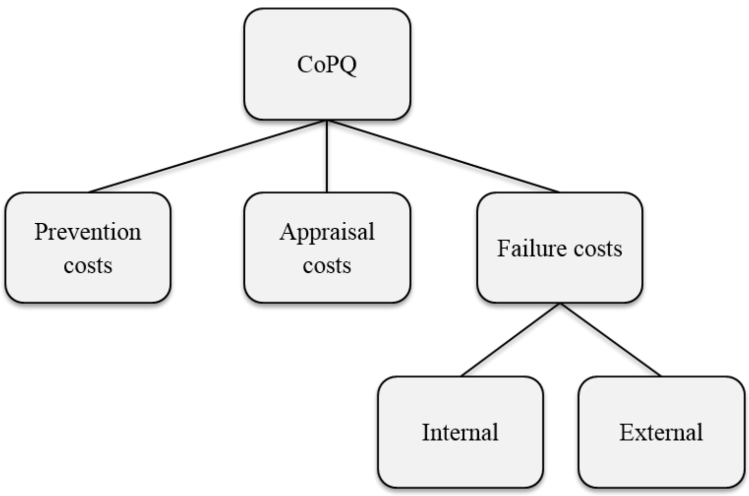

Figure 3.4 – Classification of CoPQ according to Feigenbaum (1991).

The first category, prevention costs, involves proactive activities, which prevent defects from occurring and aim for not letting any products with unsatisfactorily quality enter the market. The second category, appraisal costs, includes costs to make sure that the company manages the product's quality such as inspection of purchased material and tests in different part of the process. The third category, failure costs, can occur both internally and externally in the company (Feigenbaum, 1991). To provide better product or service quality, Feigenbaum (1991) means that companies should have the intention to decrease failure costs and increase prevention costs. Changes in focus, to work proactively with quality, will contribute towards companies spending their money in a better way (Feigenbaum, 1991).

3.2.3.2 Classification of Cost of Poor Quality according to Juran and De Feo

According to Juran and De Feo (2010), many companies seek to improve their financial condition by identifying where in the business processes costs can be reduced. The most common mistake companies make, when changing processes and cutting costs, is to not consider customer satisfaction and product quality. Companies should use CoPQ as a proof of what and why changes should be made. Regardless of which operation is affected, reducing CoPQ will affect the financial situation for the better (Juran and De Feo, 2010).

Juran and De Feo (2010) divide the CoPQ into three categories with the explanation that it facilitates which efforts to put focus on, see figure 3.5. In comparison with Feigenbaum (1991), Juran and De Feo (2010) classify the costs into appraisal and inspection costs, internal failure costs and external failure costs. They do not consider prevention costs as poor quality costs, instead those actions are seen as proactive efforts that contribute toward a better product, service, or process quality.

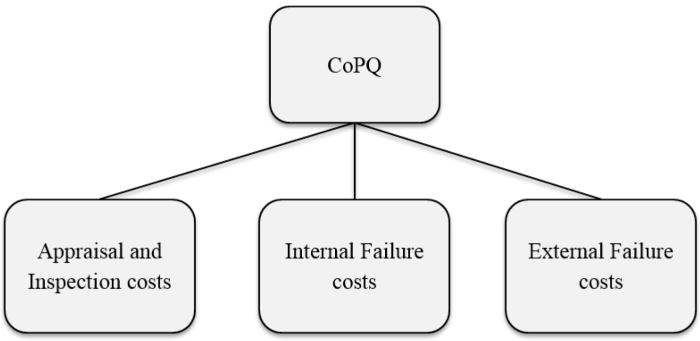

Figure 3.5 – Classification of CoPQ according to Juran and De Feo (2010).

3.2.3.3 Classification of Cost of Poor Quality according to Harrington

Harrington (1987) divides the elements of CoPQ into *direct* costs and *indirect* costs, see figure 3.6. The direct costs made up of controllable, resultant and equipment CoPQ. The other major part is indirect costs, which are defined as "*Costs that are not directly measurable in the organization's ledger, but part of the product life cycle poor-quality costs"* (Harrington, 1999, p. 227). The classification of direct and indirect costs is similar to what Krishnan (2006) labels visible and less visible costs.

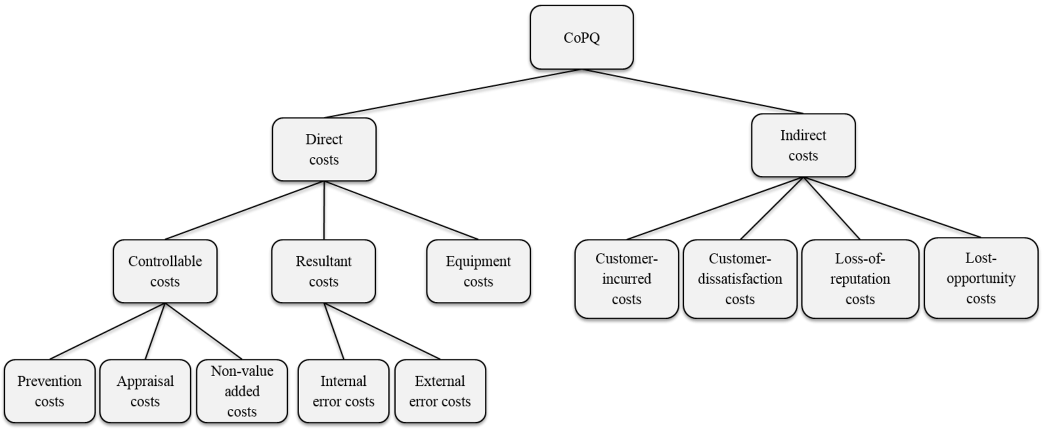

Figure 3.6 – Classification of CoPQ according to Harrington (1987).

According to Harrington (1987), the direct costs are the ones better understood. Direct costs include all the costs a company incurs because people do make errors, but also those costs incurred because management is afraid that people will make errors (Harrington, 1987). One example is overproduction, with the purpose to have products in stock if a person makes an error. Furthermore, direct costs include costs related to training people so they can do their jobs effectively. As mentioned above direct costs are divided into three categories: controllable, resultant and equipment costs. In the controllable costs Harrington (1999) includes prevention costs, appraisal costs and non-value added costs. The resultant costs consist of internal error costs and external error costs, and the last category is the equipment costs. In the direct costs, Harrington (1999) includes costs from the PAF-model (Feigenbaum, 1991) together with non-value added costs and equipment costs. The non-value-added costs are included by Harrington (1999) because the ineffectiveness designed into the business process are seen as more costly than the errors created by the process. Equipment costs are investments in equipment used to measure, accept or control a product or a service and the space occupied by the equipment (Harrington, 1987). Feigenbaum (1991) refers to equipment costs as capital investments in quality information equipment obtained to measure product quality, equipment amortization, buildings and occupied floor space.

The indirect costs consist of four major categories: customer-incurred costs, customer-dissatisfaction costs, loss-of-reputation costs and lost-opportunity costs (Harrington 1999). Harrington (1987) defines customer-incurred costs as costs that appear when an output fails to meet the customer's expectations. He describes customer dissatisfaction costs as costs that emerge when a customer is dissatisfied, bad product quality level will result in higher loss of revenue. Loss-of-reputation costs are even more difficult to measure than customer-incurred and customer-dissatisfaction costs (Harrington, 1987). Costs incurred due to loss of reputation differ from customer-dissatisfaction costs in the way that they affect the customer's attitude toward the company and not only toward an individual product line. According to Harrington

(1999), lost-opportunity costs relate to money that an organization does not realize, due to poor judgment or poor output.

3.2.3.4 Classification of Cost of Poor Quality according to Gryna

Gryna (1999) divides CoPQ as Feigenbaum (1991) into internal failure costs, external failure costs, appraisal costs and preventions costs, see figure 3.7. Furthermore, Gryna (1999) breaks down internal failure costs to *failure to meet customer requirements and needs* and *cost of inefficient processes*. The external costs are divided into *failure to meet customer requirements and needs* and *lost opportunities for sales revenue*.

Many organizations find it useful to divide the overall costs into above-mentioned categories (Gryna, 1999). However, Gryna points out that the structure may not be applicable in all cases. The company should choose a structure that suits the company.

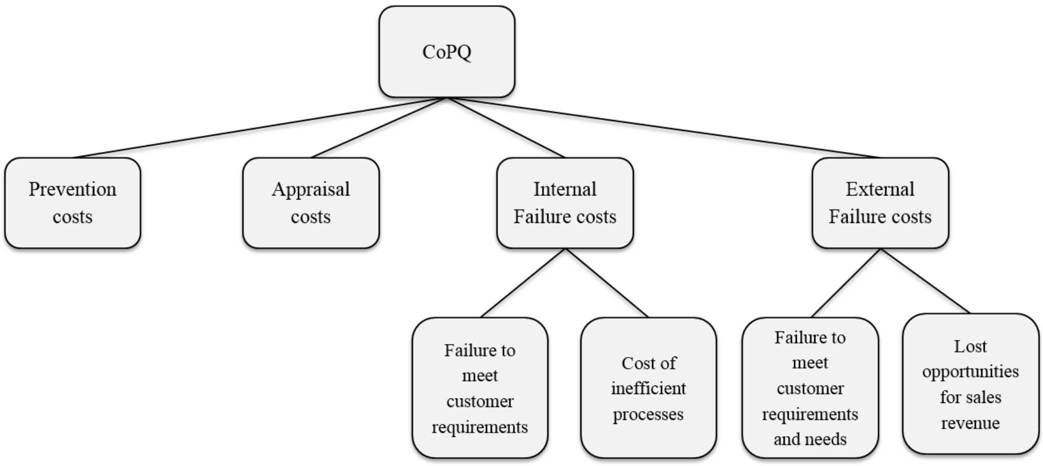

Figure 3.7– Classification of CoPQ according to Gryna (1999).

3.2.3.5 Classification of Cost of Poor Quality according to Giakatis et al.

Giakatis et al. (2001) extend the PAF-model (Feigenbaum, 1991) further. According to Giakatis et al. (2001) a distinction has to be made between *quality costs* and *quality losses*, see figure 3.8. The difference between the two costs is that quality costs add value, while quality losses do not add value and can reduce value (Giakatis et al., 2001). When a company has separated quality costs and quality losses, they should try to reduce quality losses. The distinction can expose hidden quality costs in a structural manner but also give insight about cost of conformance and cost of non-conformance (Giakatis et al., 2001).

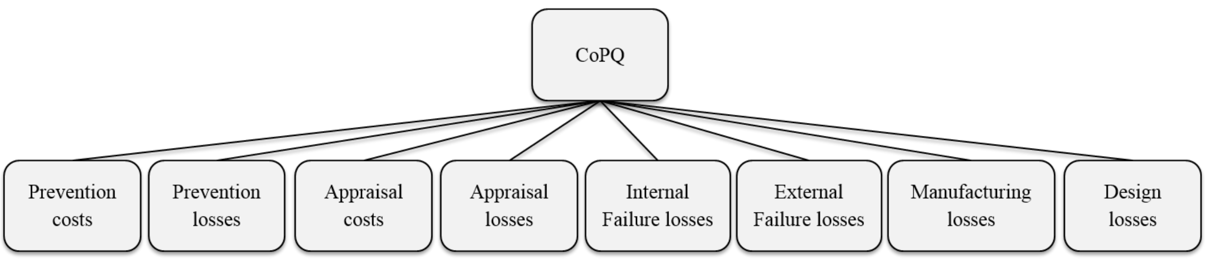

Figure 3.8 – Classification of CoPQ according to Giakatis et al. (2001).

Prevention and appraisal costs are classified as quality costs (Giakatis et al., 2001). However, since investments in prevention and appraisal activities are not always successful, there are quality losses included in these costs as well. Giakatis et al. (2001) labeled these quality losses as preventions losses and appraisal losses. Further, internal and external failure costs are classified into failure losses.

Giakatis et al. (2001) propose that there are other hidden costs beyond prevention cost, appraisal cost, internal and external failure costs. These costs are manufacturing losses and design losses, which are generated to compensate the occurrence of potential failure loss. Furthermore, Giakatis et al. (2001) argue that manufacturing and design losses are large and cannot be overlooked. Manufacturing losses appear due to inefficient use of resources, and design losses appear due to more expenses in order for new requirements to be achieved (Giakatis et al., 2001).

3.2.4 **Measurements of Cost of Poor Quality**

To be able to improve product quality and increase staff engagement for making improvements it is essential to start measuring present quality (Sörqvist, 1997). Without measurements, it is possible that the company lose crucial information that could be input to the business operations (Krishnan, 2006). A well-described quote by R.M. McNealy (1994) in (Dahlgaard et al., 1998, p. 213) is:

"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."

Accordingly, it is necessary to first define what to measure before starting the actual measurement process. Forgetting the define step is one of the main problems occurring when a company is about to measure CoPQ (Sörqvist, 2001). Further, it is essential for a company to have a common understanding about which cost parameters they consider as CoPQ (Sörqvist, 2001).

In early years, measurement of CoPQ mostly existed in the manufacturing division but during the 1990s organizations started to spread the knowledge of measuring CoPQ to other functions and businesses (Harrington, 1999). Sörqvist (2001) also comments that companies have inadequate knowledge about how CoPQ affect the total supply chain and he emphasizes the importance of measuring CoPQ in all the organization's functions. Even though measurements of CoPQ are performed more today than before, it is crucial to consider how the different cost parameters are measured in order to present reliable results. Sörqvist (2001) addresses that it is crucial to have pre-determined objectives for what the measurements should be used for. As in every quality improvement project it is essential with top management engagement (Bergman and Klefsjö, 2010). Their responsibilities are e.g. to support the quantification of CoPQ and adjust the measurement method to business operations and field of application (Sörqvist, 2001).

According to Sörqvist (2001) there is no existing model that can be used to identify and quantify CoPQ for all types of organizations. Previous research means it is hard to make generalization for which cost parameters that should be included in the term CoPQ (Sörqvist, 2001). This can be based on the fact that each organization is unique and one critical CoPQ in one organization does not have to be critical in another organization (Sörqvist, 2001). Therefore, several methods can be used to identify CoPQ such as benchmarking, measurement system, checklist and process mapping (Sörqvist, 2001; Krishnan, 2006). Sörqvist (2001) gives a recommendation to keep the methods simple and understandable. It is important that the people within the organization understands the results from the identification process and by keeping it simple, problems as longer lead-time, increased budget and risk for failures are argued to decrease (Sörqvist, 2001).

According to Sörqvist (2001), different identification methods have different benefits. A process map facilitates the overview of the entire organization and can be designed by a cross-functional team with both quality and financial knowledge. One advantage with this method is that the employees' competence and attitude do not need to be changed. One disadvantage of using process maps is the lack of continuous data. A measurement system provides continuous data and results of CoPQ. Moreover, it requires broad knowledge and strong motivation among the employees (Sörqvist, 2001). As starting point towards a sustainable improvement work is to create a process map of the total CoPQ, and then continue measuring a few critical CoPQ through a simple measurement system (Sörqvist, 2001).

3.3 The Cost of Poor Quality concept in contemporary management approaches

There are different approaches to CoPQ in different organizations. The following sections discuss two approaches, Lean and Six Sigma. Lean is commonly used in organizations today. It identifies non-value added costs (Sörqvist, 2013), and waste elimination is one of the most significant parts of the Lean philosophy (Slack and Lewis, 2011). Further on, Six Sigma is today widely spread and used in several industries, and it is argued to be the most commonly used concept for problem-solving and improvement projects (Sörqvist, 2013).

There are several similarities between Lean and Six Sigma, since both of the concepts' major goal is to improve and develop the organization by reducing wastes (Sörqvist, 2013). Furthermore, the both concepts have strong emphasis on top management support and commitment (Bergman and Klefsjö, 2010), which is argued to be an important factor to make improvements in organizations (Sörqvist, 2013). However, the concepts have their own orientations, Lean focuses on process and flow efficiency while Six Sigma focuses on improvement projects and problem-solving (Sörqvist, 2013). Each approach is presented below and how they are connected to CoPQ.

3.3.1 Lean

Nicholas (2011) says that an organization's ability to survive depends on how well it adapts to a changing environment. The author continues to describe some challenges coming with a changing environment: competitors introduce new products, industries develop new processes and technologies, and the scope of the business environment expands (Nicholas, 2011). Bergman and Klefsjö (2010) state that continuous quality improvements of goods and services are vital for a company. Further, Nicholas (2011) points out that continuous improvement is needed to be able to meet the customers' expectations. According to Sörqvist (2013), continuous improvement is the foundation of Lean. Slack and Lewis (2011, p. 89) explain Lean as:

> *"The flow of products and services always delivers exactly what customers want (perfect quality), in exact quantities (neither too much nor too little), exactly when needed (not too early or too late), exactly where required (not to the wrong location), and at the lowest possible cost."*

One of the most well-known companies applying Lean is Toyota. Toyotas foundational principles are represented with what is referred to as Toyota Production System House (Stewert, 2012) see figure 3.9.

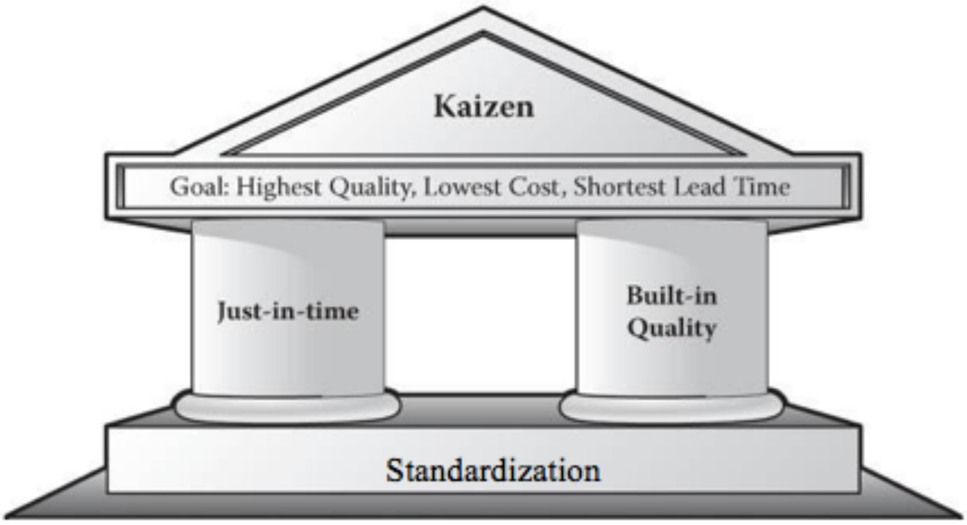

Figure 3.9 – The Toyota Production System House based on (Stewert, 2012).

Standardization is the foundation of the Toyota Production System House (Stewert, 2012). Without standardization, the house would collapse and no kaizen would take place (Stewert, 2012). Bergman and Klevsjö (2010) describe \`kaizen´ as \`changing for the better´. \`Kaizen´ consists of the symbols \`kai´, which means, "to change" and \`zen´ meaning "good". Kaizen can also be explained as continuous improvement (Stewert, 2012). The house is built upon two pillars: just-in-time and built-in quality.

Sörqvist (2013) points out that Lean can be related to CoPQ. Both Lean and CoPQ identify non-value adding costs (Sörqvist, 2013). They are also similar when it comes to how to measure different costs. Lean focuses on time and how time can be shortened (Sörqvist, 2013). Further, the author states five different ways to measure time: lead-time, throughput time, downtime and value-added time. By using measurements, waste may be visualized. Below, Lean's seven wastes are explained.

3.3.1.1 Wastes of Lean

Waste elimination is arguably the most significant part of the Lean philosophy (Slack and Lewis, 2011). Toyota Way, which is a guide with Toyotas principles, is based on the goal of identifying and eliminating waste of all activities, which is called *muda* in Japanese (Liker and Meier, 2006). When looking at a process it is often argued to have more waste than value-added activities within material and information flows (Liker and Meier, 2006). Sources of waste vary within different organizations but Toyota's mudas are argued to be applicable in almost every organization. The mudas were first described by Taiichi Ohno and are explained based on Nicholas (2011) below.

Waste from producing defects

The costs of defects in products or services include warranty and repair expenses, customers' aggravation and loss of existing and potential customers. Producers have to devote resources for inspection and sorting. Both products that need to be reworked or scrapped result in extra resources. Additional labor and material are needed if a product is defect. All labor, material and resources expenses can be seen as waste if products have to be scrapped. Defected products may also lead to reduced prices on the market, delayed production and increased production lead-time.

Waste in transportation
Processed items must, in many organizations, be moved from one location to another. Since no work is performed while the items are transported, the time spent moving items is seen as waste. Two factors can determine the distance the items must be moved and transported. First the layout of the facility, second the routing sequence of operation.

Waste from inventory
Since no value is being added to items that are waiting, inventory can be seen as waste. An increased size of inventory results in an increased size of holding costs. Holding costs include the expenses of storage space, paperwork and handling, insurance, security and pilferage. Having items in inventory is also an opportunity cost as well as an interest expense. Managers have often used inventory as a just-in-case philosophy; meaning that they have inventory, just in case of problems.

Waste from overproduction
To overproduce and make products for which there is no demand is wasteful. Some companies overproduce because they want to build inventories or keep their equipment running. While waiting to be sold, the products are kept in stock. Which result in costs and wastes associated with inventory explained above.

Waste of waiting time
Waste of waiting can take many forms. Waiting for orders, materials and items from preceding processes or for equipment repairs are few examples. Automated processes can be another case of waiting, when an operator starts an automatic machine and then wait until it is finished. Companies do sometimes try to minimize their waiting time by keeping machines running and workers busy. This may cause overproduction, which often is seen as a worse waste than waiting time.

Waste in processing
Unnecessary and ineffective steps can be part of the process itself. One example could be a product that goes through several steps. Cutting the number of operations steps could optimize the process and the waste of processing would then be decreased.

Waste of motion
Being in motion and work are not considered the same. However, work is a kind of motion that adds value or is necessary to add value. A person who is in motion the entire day, may actually just do a little work. The rest of the motion is considered as waste. The most common waste of motions in jobs are searching, selecting, picking up, transporting, loading, repositioning and unloading. These activities take time but do not add value.

The eighth waste
Sörqvist (2013) declares eight categories of waste in Lean, compared to Toyota's original seven categories. The eighth added waste is according to Sörqvist (2013) *unused creativity*, which has got attention during the last years. It symbolizes that the co-worker’s skills and ideas are not fully used (Sörqvist, 2013).

3.3.2 **Six Sigma**
Six Sigma is a methodology with a large set up of quality tools and methods, aiming to reduce unwanted variation in parameters to deliver value for customers and stakeholders (Sörqvist,

2013; Pyzdek, 2003). According to Bergman and Klefsjö (2010), the unwanted variation is a crucial source of costs, and reducing variation will save money. Originally, Motorola developed Six Sigma in the late 1980s and became a leader in continuous improvements by adopting Six Sigma throughout the entire organization (Sörqvist, 2013). Other businesses got interested and companies such as General Electrics invested lot of resources in improvement projects based on the Six Sigma methodology (Sörqvist, 2013). During the beginning of 21st century, few applicable tools from the Lean concept were integrated with Six Sigma (Bergman and Klefsjö, 2010).

Six Sigma is a concept that involves the entire organization and has different definitions depending on the specific situation where the methodology is intended to be implemented (Schroeder et al., 2008). One definition, by Schroeder et al. (2008, p. 540), is:

> *"Six Sigma is an organized, parallel-meso structure to reduce variation in organizational processes by using improvement specialists, a structured method, and performance metrics with the aim of achieving strategic objectives".*

The parallel-meso structure means that Six Sigma operates as a parallel structure with the original organization and concerns the integration between individuals at all levels and the organization (Schreoder et al., 2008). To facilitate the integration between top management and project improvement teams, Black Belts play an important role (Schreoder et al., 2008). Normally, every Six Sigma project's team leader is a Black Belt, and his/her leadership skills are crucial in order to manage the project.

One of the most important factors when implementing Six Sigma is top management commitment (Banuelas Coronado and Antony, 2002). Top management has the possibility to provide resources and training opportunities for the employees. Since many people are involved in a Six Sigma initiative, it is crucial to communicate how it works, how it will affect each individual's work, and which benefits that can be expected (Banuelas Coronado and Antony, 2002).

Six Sigma is based on a sequence of operations to improve projects and processes including following phases; Define, Measure, Analyze, Improve and Control (DMAIC) (Bergman and Klefsjö, 2010). In the define phase, the major goal is to define the problem and describe the objectives of the improvement activities (Pyzdek, 2003). This correlates with Dahlgaard et al. (1998), saying that the problem needs to be defined before measurements of the process parameters are started. According to several authors (Pyzdek, 2003; Bergman and Klefsjö, 2010; George et al., 2005), the measurement phase in any improvement project, and not least in Six Sigma, is crucial in order to measure the current system and establish key performance indicators (KPI) for the business processes. Since many improvement suggestions are based on facts, KPIs should be adapted to each company's processes. The most commonly used measuring scale is *"defects per million opportunities"* (dpmo) (Bergman and Klefsjö, 2010, p. 571).

According to Pyzdek (2003), there is a relation between sigma levels and quality levels of performance, see figure 3.10. Six Sigma aims to meet customer requirements, identify and eliminate non-value adding costs, which is equal to Cost of Poor Quality (Pyzdek, 2003). As can be seen in figure 3.10, those Six Sigma projects that seek for higher Sigma level and succeed in reaching that level will also reduce Cost of Poor Quality. The major reason to why Six Sigma's different levels are directly related to costs is because sigma levels are a measurement of error rates that cost money to correct (Pyzdek, 2003).

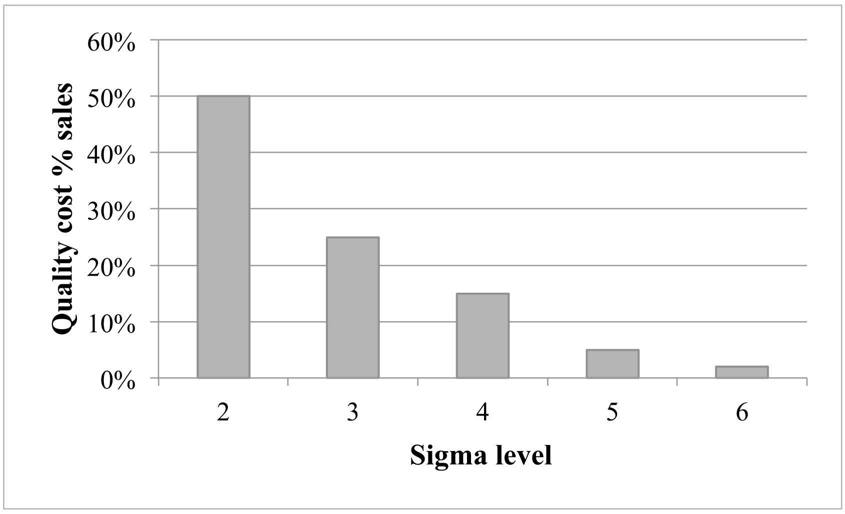

Figure 3.10 - Correlation between Sigma level and Cost of Poor Quality. (Adapted from (Pyzdek, 2003))

Compared to the different CoPQ classifications and Lean philosophy, Six Sigma uses a problem-based approach (Pyzdek, 2003). Meaning that the Six Sigma methodology starts with a definition of a problem, which will act as a starting point for the measurements. The CoPQ can, according to Sörqvist (2001), be broken down into cost drivers, which are those activities that cause CoPQ. This can be related to Six Sigma where Bergman and Klefsjö (2010) address that the methodology focuses on finding root causes of the unwanted variation to improve the quality of the operations. According to Pyzdek (2003), measurements of CoPQ will enhance the understanding about the organization's current situation regarding non-value adding activities.

3.4 Synthesis of Cost of Poor Quality classification

As previously explained, CoPQ has been discussed and classified by several authors. Even though the classifications of CoPQ differ, the PAF-model can be seen as a common base for the different classifications. PAF was the first model introduced by Feigenbaum (1991). Figure 3.11 shows a synthesis of the CoPQ classifications. It is similar to the PAF-model but it includes the perspective of Lean in which the term called waste is added.

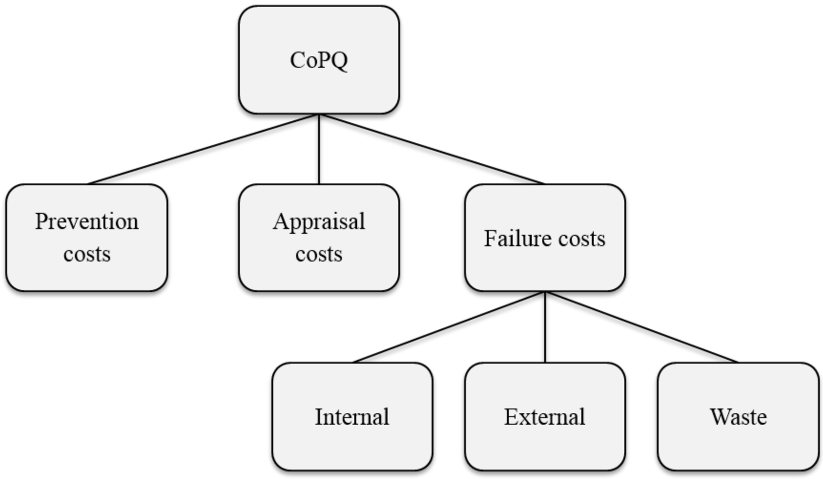

Figure 3.11 – Synthesis of CoPQ classification.

In earlier research the perspective of including prevention costs to CoPQ or not has been widely discussed. Feigenbaum (1991) includes prevention costs in the PAF-model, since prevention costs involve proactive activities which can be seen as a cost due to poor quality. On the other hand, Juran and De Feo (2010) do not include prevention costs in the term CoPQ. The authors see those actions as proactive efforts that contribute toward a better product, service or process quality. Giakatis et al. (2001) confirm this by saying that prevention costs are investments, which will improve the quality, and therefore should be excluded from CoPQ. At the time when the PAF-model was developed the idea to measure prevention costs was to compare cost invested in quality improvement with cost due to poor quality (Sörqvist, 2001). This result could give the organization an overview of their business' quality level. Considering all approaches to prevention costs, the summarized framework includes prevention cost in CoPQ.

Appraisal costs are included in the synthesis of CoPQ classification since it is seen as disadvantage to offer faulty products or services. Earlier research includes appraisal cost in the framework of CoPQ, which indicates the importance of the cost perspective. According to Feigenbaum (1991), appraisal costs means that company managers must ensure product quality, including costs such as inspection of purchased material and tests in different parts of the process.

Failure costs are included in the summarized framework and are divided into three categories, internal, external and waste. According to the Feigenbaum (1991), failure costs can occur both internally and externally in a company. Gryna (1999) divides the internal and external failure costs into further categories, but the authors of this master thesis have a similar view as Feigenbaum (1991) and divide failure costs into internal and external costs. The waste perspective is added as a category beneath failure cost. Harrington (1999) discusses the importance of including a non-value added category, which in this case can be seen as the new waste category. The waste category includes the wastes of Lean discussed in previous session.

Harrington (1987) divides CoPQ into direct costs and indirect costs. This is similar to what Krishnan (2006) labels visible and less visible costs. Within the direct costs, Harrington (1999) includes costs from the PAF-model together with non-value added costs and equipment costs. The indirect costs include customer-incurred costs, customer-dissatisfaction costs, loss-of-reputation costs, and lost-opportunity costs. Moreover, Dahlgaard et al. (1998) also consider visible and invisible costs when classifying CoPQ, which also is similar to

Krishnan's (2006) visible and less visible costs. The synthesis of CoPQ includes visible/hidden costs and direct/indirect costs in prevention costs, appraisal costs and failure costs. As discussed by Harrington (1987), Krishnan (2006) and Dahlgaard (1998) it is important to consider direct/indirect cost and visible/invisible costs while identifying CoPQ.

4 Findings

The purpose of this master thesis was to develop a tool to identify and quantify CoPQ. It has been an iterative process of studies and analysis. This section includes four parts. The first two parts present empirical findings, including expert and case study, where data has been gathered to gain practical knowledge about CoPQ. Further, the empirical findings together with theoretical framework are analyzed in the third part. The analysis aims to develop a tool to identify and quantify CoPQ. The forth part explains the verification process, where the tool is applied in a company.

4.1 Expert Study

Eight different interviewees with people working with quality have been conducted. The interviewees are experts or specialists within research and development, production, and after sale. From the interviews, it was possible to discuss how CoPQ can be used, classified, identified and quantified.

4.1.1 Use of Cost of Poor Quality

The reason for working with quality and improvement work is, according to several of the interviewees, to make money. Other reasons may be to get happy co-workers and satisfied customers. However, the main goal is still to increase the profit margins and make money. Companies do often realize that they have to improve their quality when profit level decreases and one interviewee believes that companies need to change their view of quality. According to one expert interviewee, quality is often associated with products and it can be hard to connect quality with the organization's activities. Despite this, the same interviewee argues that quality should be explained as *customer oriented operations improvement.* With this expression the companies could work towards increasing quality in all operations instead of only focusing on the product.

Several interviewees mention that it differs how companies work with quality. One interviewee explains that there are two differences between how companies work with quality depending on the potential customer. First, if a customer buys the product for private use, the company often gets a lot of feedback and measurements regarding the product. In this case, it is important to make customer research to sell the right product to the right customer. Second, if the customer belongs to another business, the focus is more on uptime to ensure that the products always work well.

One interviewee mentions that many companies do not go to the bottom with quality problems. The main reason is when a problem is solved, nobody has the motivation to continue to dig deeper into the problem. If companies would investigate problems in detail, CoPQ could have been avoided when developing new products.

CoPQ is, similar to quality, often associated with products. The expert interviewee stresses that CoPQ occurs when the organization is not working correctly, and when there are defects in processes and flows. Moreover, one interviewee states an undesirable cost as: *"The things you are doing with a product for a customer, is that you deliver in the right quantity, in the right time and with right quality. All specifications that cannot be met are undesirable costs"*. Another interviewee mentions that companies do not have goals regarding CoPQ. The only goal is to reduce costs. Table 4.1 presents different views of CoPQ, as stated by interviewees.

Table 4.1 - Different interviewees' view on CoPQ.

Interviewees	Quote about CoPQ
Quality specialist within after sale	*"It is all the costs that hit a company, visible and invisible costs that are driven by poor quality. Or the costs that are affected by poor quality."*
Quality specialist within production	*"Cost that you could have avoided."*
Quality specialist within R&D	*"Unnecessary costs, because you are not acting. They would not exist if you understood them."*
Quality expert	*"The costs that arise due to deficiencies and failures. We are having a faulty business."*

CoPQ are being seen as disadvantage costs in an organization, from all interviewees. The quality specialists within production and R&D look at CoPQ as costs that could have been avoided and would not have existed if the knowledge about them increased. The other two interviewees develop the definition of CoPQ even further. They see CoPQ as costs that are caused by poor business activities and failures. The above stated quotes indicate that people see CoPQ in different ways, which is similar to the different opinions regarding the relevance of CoPQ.

The relevance of CoPQ has been discussed during the interviews. CoPQ is, according to one interviewee, a too wide concept to work with. The informant means that the concept would need to be more specific. Moreover, one interviewee says it is challenging to convert quality into money. Instead, CoPQ would be more appropriate if measuring it as failure rate. Failures should be evaluated in the same way, independent of the cost. Another interviewee confirms this mindset. This person means that a failure is a failure no matter the cost. If a final product does not work, it does not matter how costly it is to fix the problem. Many interviewees say that quality usually is measured as failure rate.

4.1.1.1 Measurements of Cost of Poor Quality

One expert interviewee discusses and explains three different reasons why measurements of CoPQ are important. There is no meaning to perform measurements without knowing why they should be done. The first reason is to get an argument to start working with improvements. If this is the goal, the most important factor is trustworthiness in the measurement. The second reason is to see what needs to be improved and to help prioritize where to start. In this case, it is important to work in a consistent way throughout the whole organization, to evaluate factors such as rework and information sharing equally, and to have a homogenous method for measurements. The third reason is the mindset of key performance indicator, KPI, where the accuracy of the measurement is important.

According to several interviewees, organizations have ways to measure CoPQ. One interviewee argues it is beneficial to quantify the largest CoPQ before identifying the smaller. Furthermore, different functions perform measurement in the same way but with different starting positions. Production is mentioned as the function where most measurements are done. However, one informant stresses that it is more important to fix problems than to perform too much measurement. Based on the interviewee's judgment on experience from working life, companies put more efforts into measurements than into problem-solving. One informant stresses the need of establish a way of working with CoPQ otherwise it is impossible to find where in the organization CoPQ exist. There might exist costs but nobody knows what to do, since nobody knows where the costs were created. A structured working procedure would facilitate people's understanding about CoPQ and how each person can affect CoPQ reduction. Another informant confirm this by stating:

> *"CoPQ is measured high and low, but it is hard to connect them to something [the time and place in the process where they arose]".*

One expert interviewee discusses different ways to measure CoPQ. One way is to continuously create reports of different CoPQ within the organization. For instance, make reports about scrap costs in the production function. Another way is to visualize where CoPQ exist through process maps over the organization's processes. Value stream lanes and swim lanes are argued to be valuable in process visualization. The tools structure and facilitate the process map by distinguish work responsibilities and job sharing for sub-processes of a business process. The third way is to measure CoPQ from a global perspective. This can be done by identify CoPQ by following a process. To build complete measurement system to get reports is, according to the expert interviewee, not doable and not worth the time it takes. It would be more preferable to develop a routine to create process maps and use checklists.

Problems with measurements of Cost of Poor Quality

Lack of competence is one reason for why companies lack measurements of CoPQ. According to one interviewee people do not know what to measure, they need help to perform the measurements or they are used to work in another way. Further, it may be the fact that the employees do not have the energy to do it. Mainly, because lack of resources. In line with this, another interviewee highlights the problem with resources to use the measurements. Even though many measurements are done, it is not fully used because lack of resources and time to analyze it. Some companies do also have a "we do not need to measure"- mentality. Especially if the company is doing well, measurements of CoPQ seems unnecessary.

Alternative measurements

Many interviewees mention KPI as a common and good tool. KPIs are often used in organizations, however one interviewee discusses how well they are followed up. The same person says that it is the top management's responsibility to make a plan of how the KPIs should be followed up. To not lose the employees' motivation to use KPIs, it is important to have well defined and realistic KPIs.

Two interviewees questioned the alternative costs within projects. Alternative cost is seldom measured. Do companies compare what it would cost to release a product early versus improve the product and release it later? How much will a company save if they do a FMEA on a product that became faulty compared to not doing it? Conducting a product FMEA requires more work and time, which can be the reasons for not comparing.

One expert interviewee discusses whether measurement of costs is interesting or not. Instead the person argues that it is of bigger importance to measure the cost savings in the end of the improvement work. Furthermore, one interviewee mentions that proactive quality work is often done in companies. Unfortunately they are seldom followed up to see how they affect quality and the result.

4.1.1.2 Communication and Information between functions

Lack of communication and information is pointed out as a big CoPQ in several companies. As stressed by one quality specialist, it is important to have information before taking action.

One interviewee points out the importance of having the right information instead of having a lot of information. A critical factor when considering CoPQ is when information is being hidden. For instance, a company may consciously hide information because they do not want to share it with other parties.

One informant says that CoPQ is discussed more frequently within small companies. It is argued that it is easier to follow the product's value chain and give feedback between the functions in a small company. Another interviewee says that CoPQ is not discussed between functions at all. This person believes that top management has the overview of CoPQ and its impact on the organization, but the costs are not communicated on a functional level.

In many cases, the R&D function does not get any information about product/service failures from the after sale function. This means that no follow-up is done from previous projects. It is important to send information back and forth between functions. R&D may use statistics e.g. about customer claims and from a reference product. However, the project group who developed a product does not often get the information about how failures affect the company. One interviewee suggests that one way to improve the feedback is to let the person who is responsible for the component design be the same person who solves a potential problem. When follow-up activities are missing, it can contribute to decreased motivation among the employees.

Lessons learned is a concept, mentioned by many of the interviewees. The idea is to learn from previous experiences to eliminate mistakes from happening again. If no previous information is saved, the risk of unnecessary costs is high. In this case, documentation becomes a central part. One interviewee argues that documentation is important due to frequent change of employees.

4.1.2 Classification of Cost of Poor Quality

To increase knowledge about which CoPQ that are most important to identify and consider in the tool, the interviews started with an open question about critical costs. Therefore, this section starts to present the critical costs of Cost of Poor Quality that were discussed by the interviewees. Furthermore, the interviewees' views of visible and hidden CoPQ are discussed. Lastly, the CoPQ parameters identified during the interviewees are divided into three functions; R&D, production and after sale. All cost parameters identified are presented in appendix III.

4.1.2.1 Critical costs of Cost of Poor Quality

Critical CoPQ are seen as high costs by several of the interviewees. One interviewee discusses the correctness of that, even though a fault is cheap to correct, it may be critical if the failure rate is high. A more proper way to work with CoPQ is to use both money and failure rate.

Several other, more or less critical, costs were mentioned during the interviews. First, waiting time was one frequently mentioned critical cost. Waiting time occurs in several processes and is mostly due to that employees/machines do not have sufficient prerequisites to perform their/it work. Another cost discussed was not planned overtime, which is seen as CoPQ because of several reasons. First, there is a possibility that employees lack their motivation to work if they constantly are asked to work more than planned. Moreover, it is common that companies need to pay more to people who are working overtime, which increases the company's costs.

The majority of the interviewees discussed if starting new product development projects is higher than solving quality issues of older products. To not consider quality issues before starting new projects can result in high CoPQ. According to the interviewees, to be able to deliver high quality products, the top management needs to consider quality in the project budget. Therefore, lack of money can be a source of bad quality that in turn can increase cost in later phases of the product's value chain. This can therefore be seen as a critical CoPQ.

A dissatisfied customer is critical, especially since the digital effect is much larger today than before. This causes cost in goodwill, both commercial and technical, for a company, which is explained by one expert interviewee as a major CoPQ. Goodwill can be explained as a cost, which companies pay to dissatisfied customers to make them satisfied. According to the interviewee, goodwill is hard to calculate since it is an indirect cost that only occurs when the customer is unsatisfied. However, the interviewee stresses the importance of trying to estimate goodwill to be able to prevent unpredictable customer complaints.

Identifying claims and what causes the problem of the product is a further critical factor discussed by one of the interviewee. For instance, customers usually conclude that the problem concerns the product's hardware instead of the software. This can result in lot of money being spent on unnecessary recalls. According to the interviewee, there could be several reasons leading to wrong problem identification, such as lack of understanding about how to trouble shoot the product and the fact that it is normally harder to test the software compared to the hardware.

4.1.2.2 Visible and hidden Cost of Poor Quality

Visible and hidden costs were discussed during the interviews. Visible costs are often easier to identify than hidden costs. Warranty costs is one example on a visible cost that is easy for top management to influence. It might be a good start to work with warranty costs if the goal is to decrease costs. Hidden costs are often covered by other costs. Few of the visible and hidden costs are discussed below.

The largest invisible CoPQ are, according to the expert interviewee, the gap between the accepted level and the possible level of the product/service quality. The possible level is where the organization could reach if everything would be perfect. However, these costs are hard to find. According to the expert interviewee, many organizations try to find them by looking into their processes. Therefore, process maps with value stream lanes and swim lanes are valuable tools when trying to analyze an organization and its processes.

Argued by one of the interviewees, time can be seen as a hidden cost. One example is when a project takes longer time than expected, the extra time required will contribute to CoPQ. Another CoPQ connected to time is, according to two interviewees, when lack in time result in not fully completed work tasks.

Another hidden CoPQ is the decision to buy or produce different products and parts within the company. If wrong decision is taken, unnecessary costs may arise. Furthermore, the culture within a company is a factor that is hard to measure. There could exists an "I don't care"-attitude or "I don't dare"- attitude throughout the company. It is about motivation, engagement and responsibility between the employees. The company culture and employees' motivation are hard to measure and visualize. The following paragraph elaborates on three different ways to identify hidden costs.

First, the expert interviewee states that it is beneficial to identify invisible costs by working from a problem. The hidden costs can then be found by looking into alternative costs that may arise, e.g. What could we have done during the time we spent on replanning? What did we lose? Other potential effects? The interviewee states that it is easier to find these costs by using a problem than looking into a process in general. Second, the expert interviewee discusses another way of trying to make invisible costs more visible. The idea is to have a system that exposes all problems. A system where buffers are reduced and problems become visible directly when they arise. Third, benchmarking and best practice studies are mentioned as methods to make invisible costs more visible. The same informant explains that employees can be valuable to identify invisible CoPQ. The reason is that the employees have information about problems within their function.

4.1.2.3 Cost of Poor Quality divided into functions

The three different functions studied experience different CoPQ, examples presented in table 4.2. The product's value increases along with the value chain, which also means that problems occurring later on in the supply chain will be more expensive to fix. One interviewee summarizes how R&D and after sale relate to CoPQ by saying:

> *"R&D focus ahead and quality is there to secure. After sale works to ensure that the customers are satisfied and that everything is working well. After sale gives information back to the head office".*

Table 4.2 - Examples of CoPQ within different functions and common CoPQ based on interviews.

R&D	Production	After Sale	Common
• More generations of prototypes than expected	• Scrap during production	• Warranty	• Problem-solving time
• Products sold to not suitable customers	• Unplanned set-up time	• Claims	• Loss of Motivation and Engagement
• Rework	• Stop in production	• Repair	• Person injury
• Redesign	• Equipment disturbance	• Goodwill	• Over-time
• Unspecified development process	• Rework	• Campaigns	• Lack of resources

Before dividing different costs into the three different functions, some common CoPQ will be explained. These costs and factors can be seen as common since they can appear in all three functions.

Work related absence due to illness and person injury is CoPQ that affect all three functions. Except from sick pay, the company needs to make sure that there is staff, with right competence, to cover when someone is absence due to illness. Furthermore lack of motivation and engagement are two factors contributing to CoPQ. Another factor that might lead to CoPQ is low worker efficiency. Moreover, education is a highly important factor, when trying to avoid CoPQ. If there is not enough education, it might end up in problems.

Research and Development

According to the expert interviewee, it is hard to identify and measure CoPQ within the R&D function, especially if the organization is small and has an unspecified development process.

It is then impossible to receive the information needed about the process. However, realizing that the product development process is unspecified is one step toward identifying CoPQ, since the weaknesses can be visualized and bring value to the company.

One specialist within R&D mentions the fact that there are many factors outside the R&D function that affect the result. For instance, there might be problems with customer specifications. If the specification is wrong according to the customer needs, the product will end up not satisfying the customer. If the information and communication between marketing/sales department and R&D is bad, problems might arise. One example is to sell products to customers that are not suitable for that type of product. Another informant stresses the problem of risk-taking within R&D; sometimes it is necessary to take shortcuts, which may result in CoPQ.

Two interviewees talked about prototypes and pre-serials as CoPQ. If there is a need of more generations of prototypes than expected it is a CoPQ. Nowadays, prototypes can be validated and verified digitally, which reduce the number of prototypes. To make more prototypes than necessary is one type of reworks. Several interviewees emphasize rework and redesign as typical CoPQ within R&D. Anyhow, it could be difficult to distinguish the iterative process in design phase and the unplanned rework. The iterative process of drawings, designs etc. are planned processes and cannot be seen as CoPQ. But when a development activity is remade and not part of the development plan, it will lead to CoPQ.

During one interview the resource capacity was discussed. One interviewee wonders why companies do not use their resources to employ more designers, who can solve problems. The person means that lack of resources is a large CoPQ, which could be solved easily. One problem could be, according to another interviewee, that the works are not reported completely. For instance, the only cost that is reported as a CoPQ is when an employee needs to repair a design flaw.

Not updated instructions is another CoPQ mentioned during the interviews. One example is when R&D uses previous instructions even though changes have been made. The company needs to make sure that they have the right methods, correct work instructions, and that production has the right processes for the new design. To avoid CoPQ, Failure Mode Effects Analysis (FMEA) can be used and several interviewees discuss the tool. When working with FMEA, it is important to have a dedicated group, who work with the FMEA from the start of product development process to the end customer.

Production

Scrap is the most frequently mentioned CoPQ within the production-function. Other examples of CoPQ are: equipment wear, production downtime, equipment collapse, surplus stock, low inventory turnover and delivery disturbance. Furthermore, set-up time is a complicated cost. On one hand, it may be less expensive to avoid one reset and produce more products than needed. On the other hand, the company gets unnecessary products in stock.

During the interviews there has been discussed whether inspection in the production process is a CoPQ or not. On one hand the inspections are necessary to ensure product quality and increase the risk of selling damaged products. But on the other hand, too many inspections in the production process are not preferable as it might lead to high CoPQ.

Transport damages in production is another type of cost mentioned by several interviewees. These damages may be costly themselves, but the time it takes to investigate why and where the product is damaged is also unnecessary activities. Transport damages are seen as causes to costs like scrap and rework.

After Sale

CoPQ is often discovered within the after sale function. According to one interviewee, after sale is the function that talks most about CoPQ. The reason is that in after sale the costs become visible. Analysis of warranty data, outcome from field test and important customers claims are just a few factors that after sale are working with.

Stated by many informants, warranty cost is a major cost of CoPQ. Sometimes, the warranty costs are higher than the design costs. The biggest and most expensive warranty costs are often the ones analyzed first. Warranty cost can, according to one informant, be estimated as a percentage of total turnover. Another informant thinks it might be difficult to estimate warranty costs. By looking at prognoses and statistics it may be easier. Measurements referred to warranty can be done by measuring; the number of days before customer complaints are received, customer satisfaction and retail satisfaction. Even though warranty is not measured in time, the time to handle warranty is critical. Since the warranty is depending upon when a solution to the problem is ready, the longer time it takes, the more costly the warranty becomes.

Another issue related to time is the lead-time to solve quality issues. Usually, it is the after sale function that receives customer claims and passes the information further to the quality manager. This person decides whether the claim is related to a quality issue or not, and if that is the case the quality manager starts an internal problem-solving project. The lead-time to solve the quality issue and identify where in the process it occurs can therefore be seen as a CoPQ. The faultfinding process is depended on the claim information and in turn the person who wrote the failure report. One informant stresses the importance of having correct claim information in order to avoid that further CoPQ occur.

Two interviewees mentioned poor repairs as CoPQ, which belong to the after sale function. For instance *"repair-repair"*, meaning to do repairs more than ones and also to use poor methods for repairs.

Goodwill is a cost depending on product failure or customer claim. Goodwill is used to make customers satisfied while the problem is being solved and it can be divided into technical and commercial goodwill. Further CoPQ that is used to satisfy customers is campaigns. Campaigns can be described as an action to compensate faulty products during a certain period of time. Goodwill and campaigns can be very costly for the company and create a lot of irritation and frustration.

4.1.3 **Inputs for identifying and quantifying Cost of Poor Quality**

The interviews gave a lot of valuable information regarding how to develop a tool for identifying and quantifying Cost of Poor Quality, further mentioned as "the tool". Costs that are beneficial to visualize and how these could be identified are discussed below.

One specialist within an R&D function says that the accuracy of the tool does not need to be perfect. The reason is that much of what is done in the R&D function is based on adjustments and not on facts. Another expert interviewee claims that the tool has to be accuracy. Otherwise it would not be reliable.

To be able to have knowledge and understanding about where in a company a CoPQ arises, it is important to visualize CoPQ. All interviewees discussed that CoPQ should be used to base decisions on facts, and therefore CoPQ should be visualized to top management who has the power to allocate resources and make improvement actions. Almost all the interviewees agreed that the most important costs to visualize to top management are the biggest costs, the costs that hurt the company most. One interviewee means that top management is interested to see where in the company the costs arise, since it makes it possible to specify the project budget. However, the interviewee thinks it would be more valuable to see in which phase in the value chain the costs arise. On the other hand, another interviewee says that the causes to the costs are more interesting to visualize than where they arise. Furthermore, it is preferably to have a short time period between the cause of the problem and when the problem is visualized. This would give the possibility to improve the product/service faster than if the time period was longer.

The expert interviewee discusses which CoPQ in the company that should be analyzed in the tool. These CoPQ need to be costs already measured by the company. There would be no time to start measuring anything new. Costs have to be available in an existing measurement system. The tool should, according to the same interviewee, analyze costs from deviation and rework reports. From these reports the CoPQ can differ in their ability to be assigned a cost and it could therefore be beneficial to analyze them as failure rate.

Aligned with the section above, the first step in the identification process should be to investigate what kind of failure data that exist in the company. Using checklists can according to another interviewee, facilitate the identification process. The same interviewee discusses the possibility to divide CoPQ into clusters where each cluster could give a broad picture of the CoPQ situation. As stated by one interviewee *"Start with scrap in production. It will give a hint"*. The second step would concern after sale and warranty reports, since it will give information about customer claims, data that is usually visible.

One expert interviewee discusses the possibility of highlighting poor quality without measuring it in money. For instance using interviews and surveys. A survey can also be preferable when doing studies in a company from an outside perspective. Asking people about problems in their every-day work and how much time it takes, could give ideas and examples about waste and non-value added activities could be identified. Then it would be possible to estimate what these problems cost a company. The problem is, according to the same expert interviewee, that a survey might not be as reliable as needed. However, a more exact analysis of CoPQ would require studies and observations of the processes. To get a reliable result, measurements need to have a fair frequency and a certain number of measurements need to be performed during a certain time period to be able to see trends.

4.2 Case Study

The single case study was performed at one company located in the southwestern parts of Sweden. The company is a subcontractor of rubber and plastic products. This section presents the findings from the case study including a brief presentation of the company, a detail description of the converting production process and how the company uses the term CoPQ. Finally it describes what CoPQ that was found within the specific functions. Since the case company does not have a clearly R&D function, the case study will consider the process planning department as a substitute to R&D because there are similarities between these functions, see figure 1.1.

4.2.1 Organization description

The case company follows a functional organization structure and the responsibility to make decision is equally distributed on managers of each function. The organization exists of a number of functions where collaboration between the functions contributes to satisfy the company's 1400 customers, globally located. An overview of the organization is visualized in figure 4.1.

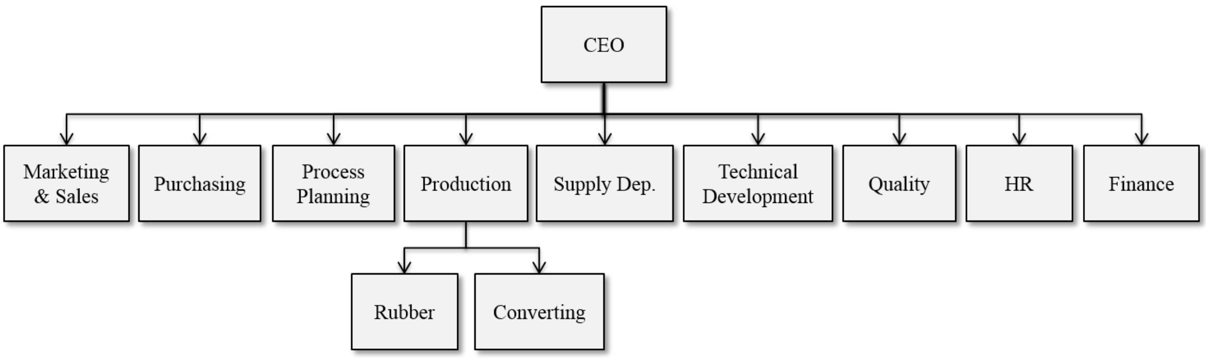

Figure 4.1 - Organization chart visualizing the departments.

The marketing and sales department has close contact with the customers and sells products to both current and future customers. They need to collaborate with both customers and production processing department in sense of matching customer requirements of the product to company's capacity. Because of the case company's wide offer of different articles, the case company needs to be flexible in the production process and adapt the production tools to each article. Therefore, the process planning department makes adaptations and modifications of the product constructions to meet the production capabilities but also development of new production tools to meet the article characteristics. Further responsibilities for the process planning department are making calculations of possible new articles including material consumption, article price and appropriate production process. This department together with production department decides the most efficient production flow and creates structures of working procedures and instructions. When there is a completed drawing with tolerances, material and design, it is ready for production. The production department is divided into two divisions for each production process: rubber process and converting process. For each production process there is one responsible production manager, who consider the most efficient way to produce the product, make production plan and allocates resources. Further results presented will only consider the converting process since it was argued to be a suitable limitation in relation to the master thesis time period.

Furthermore, the supply department involves storage and logistics for both in-coming materials and out-going products. The supply department is responsible for managing the customer system of bookings in advance and order verifications. Moreover, the technical department consists of three different divisions included development of new products, development of new rubber characteristics and adaption of production tools for the product. It is common that the case company gets an order with attached drawings, but to ensure the case company follows the technical development and innovation they are in need of the technical department.

The quality department has an overall responsibility of product quality, making sure that customer requirements are fulfilled but also ensuring that environmental requirements and legislative demands are followed. The quality manager is responsible for handling the information regarding customer claims. Further responsibility is to analyze the claims to ensure lesson learned throughout the organization.

Since the case company is a subcontractor supplying different customers and industries, they usually receive a product order from a customer, including drawings and product characteristics. This means that it is the customer who is the owner of the product drawing and the case company's mission is to meet the requirements and produce the ordered product. Figure 4.2 visualizes the general processes a product follows when serial production is approved.

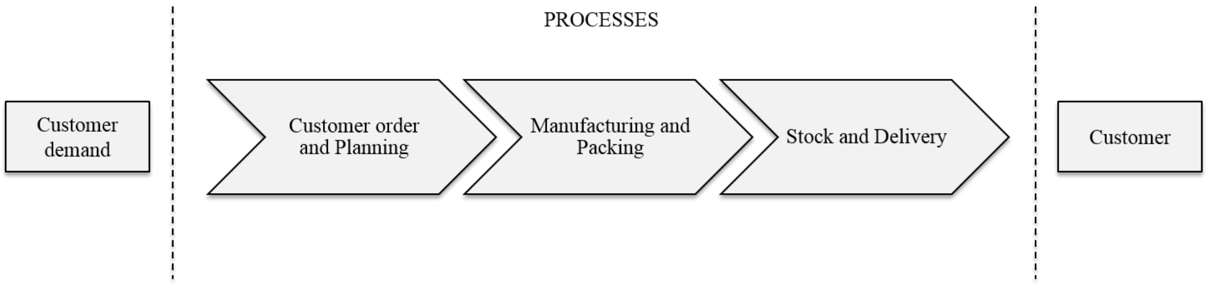

Figure 4.2 - General processes customer order to delivery of product.

4.2.2 **Production process**

The case company needs to be flexible in their production process to meet all customer needs. Therefore, all products in the converting process are made to order, meaning the finished products are not stored long time before distributed to the customer. In figure 4.3 a process map visualizes the processes toward a final product.

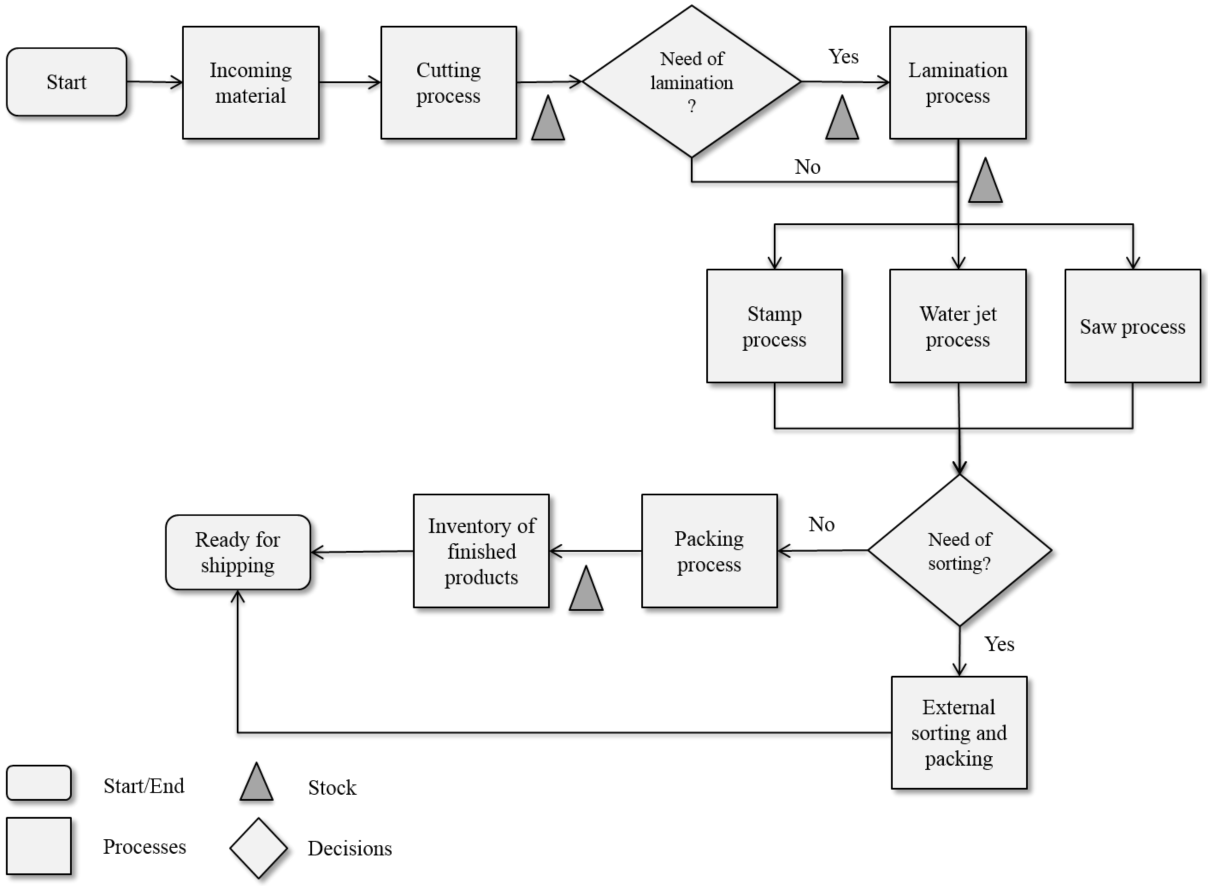

Figure 4.3 - Process map for converting process.

As can be seen in figure 4.3, independent on product type, the products follow almost the same production process. What differentiates the processes is the production step after lamination, where the product either goes though the stamp, water jet, or the saw process. At each production step the operator is responsible to produce products due to customer orders and drawing characteristics. If a product cannot be produced with current production tool and settings, the operator has the responsibility to change production tool and make tests to verify product requirements and tolerances. This procedure is manually documented and saved in binders for one year, aiming to be used to support large customer claims. Even though there is information about product characteristics and previous tests, the operators must guess regarding product tolerances, which is one of the main problems the case company is facing.

To keep the flexibility to meet all customer orders, the case company has decided to have high inventory of materials and products, from incoming material process throughout the production process until the inventory of final products. This means there is lot of capital tied up in products during the production process. The material in stock in between the production processes does not contribute to increase product value, and can be seen as CoPQ.

The most critical process step is the water jet process. It is maximally utilized and there are limited staff capacities with right competence to operate this process. When competence is missing and customer demand increases, this process suffers and it might happen that the customer orders cannot be met, which in turn decreases the delivery reliability and profit.

After the products have been produced in either stamp, saw or water jet process, the products are ready to be used. If this is the case, the operator packs the products directly. However, there could be remnant material on the products, which need to be removed. Those products are passing a sorting and packing station where staff hired from a staffing company make the adjustments and packs the products.

4.2.3 Use of Cost of Poor Quality

According to the interviewees the case company does not use the term Cost of Poor Quality in their operations. In addition, the quality manager is the only person participating in the study, who has knowledge about the term's meaning and importance. Instead of using CoPQ the case company uses one overall key performance indicator (KPI) to measure profitability, namely the relationship between number of customer claims and turnover. According to the production manager, three measurement factors are used to present current state in the production. These three factors are availability, plant utilization and quality. The quality manager would like to see further measurements in the organization's processes, at least in the production process. It would improve the decision-making in the organization, since decisions could then be based on facts, which in turn increases the reliability towards the customer.

According to the quality manager the company tries to visualize quality issues to all employees at different levels in the organization; the management team, operators and designers. Quality issues are mostly due to external, or internal, customer claims and each claim is processed equally in the company. Independent on context the issues are being reported in a common business system. Each claim is presented in a structured way on pulse meetings where people concerned are gathered and the quality manager addresses the importance of people's participation. These meetings are held in an environment close to the daily operation activities, which facilitates the possibility for participation. Each production team is responsible for considering the information about the claims and make improvement suggestions. According to the production manager, this will increase staff engagement but also improve the understanding about quality throughout the organization.

4.2.4 Cost of Poor Quality classification

During the different interviews several Costs of Poor Quality that have been identified, both visible and hidden costs. The cost parameters are presented based on respective function, either in process planning, production or after sale. In addition, there are cost parameters occurring in all functions, which are presented as Common CoPQ.

4.2.4.1 Process Planning

According to the production manager it happens that product drawings are incomplete when they are delivered to the process planning department. Therefore the drawings need to be returned to market department for correction or complementary, which causes rework for both sales and production employees. Several interviewees such as process planners and team leader for the stamp process confirm this, who all emphasizes the challenge to manage incomplete information from the marketing and sales department. This also contributes to longer lead-times until the information is completed. According to the team leader the sales department does not considers material size when developing the production tool, which results in higher amount of scrap. According to one of the process planners it is not only the communication and information from marketing and sales department that is lacking, but also information from top management.

> *"It is decided who is going to do which job but at the moment we do not work according to the plan, due to lack of information from top management".*

One of the process planners continues to say that the main reasons contributing to incomplete information are lack of communication and lack of interest among staff.

4.2.4.2 Production

The case company has a lot of rework in the production process, for instance when there is a problem on one machine and the operator does not succeed to produce the products planned, he/she is forced to reproduce products. In present, the case company lack measurement of the rework cost in production but estimation is that the reworking cost is connected to man-hours. According to the quality manager the man-hour cost can be calculated through a standard cost, only distinguishing blue-collar and white-collar workers.

Time spending on rework varies throughout the production process and fluctuates week to week. According to the team leader on stamp process the rework varies from day to day. According to the production manager, most of the reworks contribute toward scrap. The products are hard to adjust after a production process, instead the products are being reproduced and the damaged products are being wastage.

During the walk in the production process, it could be observed that there are many processes which contribute to a high amount of scrap. Most of the scrap occurring in the production line is due to lack of functionality, material waste or product damages occurring at customer field. According to the production manager a product is designed with respect to the material wastage that remains after a production process. The production manager addresses that the total scrap is being weight and calculated on month basis with relation to turnover.

According to the majority of the interviewees, machine shutdown is the most common issue in the converting process. There are at least one stop every week in production. Some smaller issues normally cause these stops and the lead-time to fix the problem is short. In case of larger machine problems and shutdowns they are reported in a failure system, but lack the perspective of the time when the machine was shutdown. One operator addresses that a total shutdown occurs rarely, but smaller machine issues are occurring every day. According to the production manager, machine shutdown is not a big problem since there are other machines with equal functions that could cover the production demand. This is closely linked to the utilization rate of the production equipment. Since the case company produces a wide range of products and details, it requires high flexibility in the production process in order to meet customer orders. According to the production manager, this is the reason why the utilization rate of production equipment is not maximized, which also seems to be accepted throughout the organization. The quality manager says:

> *"It is almost impossible to cover all details, instead we are flexible to meet new orders. The production machines are not expensive to have standby."*

The production machines have various operating cost and their physical size varies. Anyhow, according to the quality manager it could be possible to make an assumption of the operating cost for all machines in relation to the space utilization of the facility. Additionally, the depreciation of machines and its unplanned maintenance cost have to be considered. The case company has the possibility to make continuous maintenance of all machines. If a larger problem occurs and the case company does not have the possibility to make the maintenance, an external firm is hired.

4.2.4.3 After Sale

According to the quality manager the most common cost in after sale regards customer claims. A customer claim includes several cost parameters such as free of charge replacement of products, freight charge, administration cost and sorting cost. Both administration cost and sorting cost can be charged from the customer. When a problem occurs with one of the case company's product at customer field, the quality manager needs to drop the daily work task and start to process the customer claim. The manager's mission is to delegate the claim information to the responsible division and involve right people to solve the problem. Normally, the customer needs an answer within the next 24 hours. During this time the case company needs to ensure that no more incorrect products are delivered to the customers. Since the case company's products are important components for the customers' business it is crucial to replace all the damaged products quickly. Supplying the customer with new products is cheaper and less time consuming than making returns and investigating if the defected products can be corrected, which is addressed by the quality manager. However, to have the possibility to learn from mistakes and ensure the customer claims are fairly assessed, the quality manager states that the case company usually makes returns of all defected products from the customers. This is done after supplied them with new products.

Compared to returns and reproduction, the number of recalls is fewer. The quality manager states that twice a year he has to present the risk level of recalls in front of the top management. Furthermore, the quality manager states that repair are less frequent but occur mostly for expensive products. According to the quality manager the case company lack in knowledge about this cost but they desire to keep better track on it.

What companies can use as allowance toward the customers are commercial or technical goodwill and campaigns. According to the quality manager, these costs are rarely an issue the company needs to consider. It has happened that the case company made an internal decision about financial compensation to the customer, which is classified as a commercial goodwill. He confirms that product campaigns have been used historically to satisfy customers in the short-run. During discussion, it was realized that it could exist goodwill that are not registered in the system. It is a consequence from sales department taking own initiative.

According to the quality manager, in the present situation it is difficult to track the products/packages after it has left the inventory of finished products. As a result of lack in traceability it is challenging for the case company to have knowledge if there remains damaged material or products in the supply chain.

4.2.4.4 Common CoPQ

To motivate employees the case company, not at least the quality department, has worked hard to make people aware of internal and external customer claims. It is not until the employees have awareness of the quality issues that improvements can be made. One operator states:

> *"I feel motivated in my work, I have lot of responsibilities. But I experience that my voice is not heard in all situations".*

A category concerning all functions is communication and information sharing. According to the process planning manager, production manager, and quality manager the most common ways to communicate with other departments are through emails or telephone calls. Within the production division the process is divided into different sub-processes where each sub-process has one team leader. This person processes all information given from the production manager and communicates the information to the colleagues within the sub-process. As mentioned in section 4.2.3 Use of Cost of Poor Quality, the team leaders together with production manager, production planner are being gathered twice a week on pulse meetings to discuss problems of mutually interest. The quality manager has the overall responsibility on the pulse meeting, make the planning and call the colleagues to the meeting. According to one of the process planners the pulse meetings are not held to only consider external and internal claims but also when a new article are planned to being produced. This is done with the intention to prevent mistakes from happening in the first place.

Besides pulse meetings the production manager addresses that the information communicated mostly concerns production activity. The person believes that personal motivation and presentation increase through involvement and responsibility among the employees. Therefore, each week the production manager presents results from the previous week including delivery precision, past week's turnover etc. Further, the employees within the production process are required to observe the information about the claims given during the pulse meetings. According to one process planner bad communication is one challenge the case company is facing since it contributes to lack of information regards drawings and product tolerances.

One process planner states that the case company's intention is to have an instruction for each production process to facilitate the daily work for the operators, but also to be able to control the work processes in an efficient way. At present, there is not an instruction for every production process.

According to the production manager, new employees are trained to perform their work tasks. The employees also get support from an experienced employee the first couple of weeks. An issue affecting the daily work for production manager is rescheduling because of absence due to illness. Since the staff is educated to operate on specific machines, there might not be enough staff to cover critical work tasks. This can result in reduced production capacity and decreased possibility to meet customer order.

Furthermore, the quality manager addresses that one common cost factor for all the functions is the administration time or -cost needed to handle all non-value adding activities such as change of passwords that have been expired, understand IT-portals, unused software license etc.

4.3 Analysis

Customer satisfaction is the foundation of good product or service quality (Dean and Bowen, 1994). High quality also results in increased profitability and customer demands (Sörqvist, 2001), which are two important factors engaging companies. To increase product and service quality, a company needs to consider what non-value adding activities can be eliminated (Sörqvist, 1997). Normally, these activities are connected to Cost of Poor Quality (CoPQ). CoPQ exist in the total supply chain and top management is mostly interested in the largest costs and where in the company these arise. Juran and De Feo (2010) stress that CoPQ should be used as proof of what and why changes should be made. From the empirical findings and the current literature it was concluded that there are no current model or tool for identifying CoPQ in relation to the different functions. Hence, a tool that identifies and quantifies CoPQ is appropriate. Figure 4.4 visualizes the product's supply chain where the highlighted boxes are the functions considered in the tool.

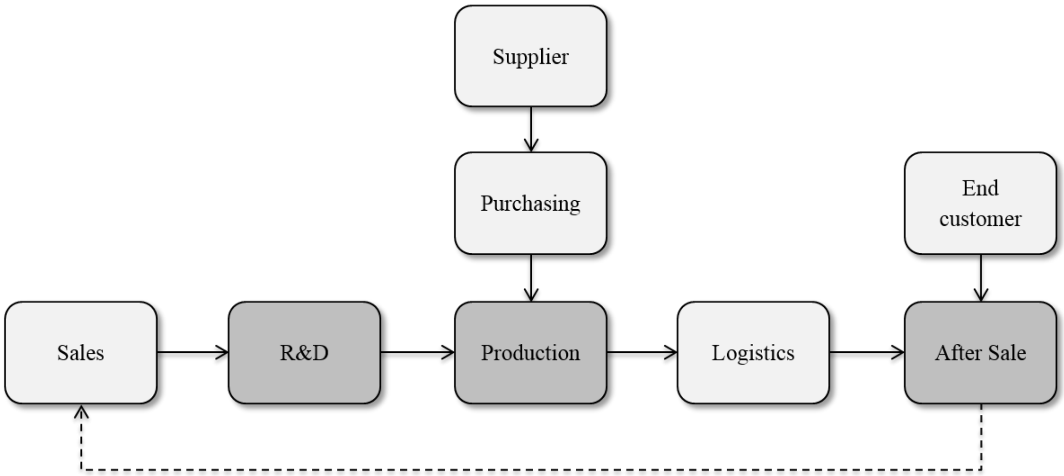

Figure 4.4 - The product's supply chain and the considered functions in the tool.

Further paragraphs present the analysis of how companies use CoPQ and what classifications and measurements of CoPQ are appropriate. Lastly, one section considers the developed CoPQ tool included its content and how it should be used.

4.3.1 Use of Cost of Poor Quality

In order to develop a tool for identification and quantification of CoPQ, it has been necessary to investigate how companies use the term CoPQ and their knowledge about it. It has been seen from the empirical study that individuals with different backgrounds and work experiences have different views of the term CoPQ and its meaning. Despite this, there are several common denominators in the views such as the CoPQ are costs that should not exist if a company's processes were perfect, and reduced CoPQ would lead to improved product or service quality and increase profit. Both Sörqvist (1997) and Juran and De Feo (2010) discuss the fact that CoPQ must be considered in the business operations and must be reduced to be able to increase profitability and competitive advantage. Using CoPQ does not only give advantages in increased profit margins, it is also beneficial to use in order to base decisions on facts. This could be a further argument for the quality manager in the case company to use in order to engage top management in the CoPQ concept.

From the empirical findings it was concluded that individuals have various experiences about quality management in different business industries and in different areas of a company.

Therefore, their knowledge about which cost parameters that are included in the term CoPQ is connected to the specific function that each individual experience most. During the case study it was seen that staff working with quality at daily basis, such as quality manager, did have better knowledge and understanding about CoPQ and its effects compared to operators in the production. This is confirmed from the expert study, that top management is able to see the big picture of CoPQ, and therefore their knowledge about the term increases. A consequence, of lack in understanding of the term, could be that the company loses the possibility to reduce CoPQ in all business operations. Both the empirical findings and the theoretical framework show the importance with a common understanding about the CoPQ term throughout the company and which cost parameters to consider as CoPQ. This involves all position levels in all functions. The company could create their own view of what they consider as CoPQ, just as long the management team guides the company in the same direction. Harrington (1987) discusses the fact that working towards decreased CoPQ also involves changes in quality mindset within a company. Everyone in the company needs to understand why CoPQ is important and its effects on the product/service quality.

Furthermore, one thing the case company works regularly with is customer claims. All claims, from internal and external customers, are presented in pulse meetings where the quality manager involves respective team in the production. It is the team's responsibility to find a solution. Customer claims are in a direct relation to CoPQ and according to Dahlgaard et al. (1998) and Krishnan (2006) claims are visible CoPQ. Most of the CoPQ identified in the case company could be related to the external customer claim report such as sorting cost, freight charge, free of charge replacement etc. While studying the "Cost of quality iceberg" (Krishnan, 2006) and compare it to the case company it could be seen that the company mostly considered the visible CoPQ such as scrap, claims, and inspection. The case company lacked in knowledge about the hidden CoPQ such as equipment failures, extra operations and ideal time. This weakness might be an effect of that CoPQ is not used in the daily operations. However, in order to include all CoPQ, and if the company wants to improve their competitiveness, it is crucial to consider both visible and hidden costs (Krishnan, 2006; Dahlgaard et al., 1998).

4.3.2 **Classification and Measurement of Cost of Poor Quality**

Feigenbaum (1991) was the first person to classify quality costs into the model called PAF, which represents prevention, appraisal and failure costs. Since then, the PAF-model has been widely used by several authors. In the theoretical framework, a synthesis of CoPQ classification is presented which considers the presented authors' views of CoPQ, see figure 3.11.

From both current literature and the empirical findings it was discussed whether prevention costs should be seen as CoPQ or not. Feigenbaum (1991) considers prevention costs as CoPQ. Prevention costs involves proactive activities, which prevent defected and unsatisfactorily products to enter the market. Several authors did not included prevention costs since they do not consider it as a poor quality costs (Juran and De Feo, 2010; Giakatis et al., 2001; Sörqvist, 2001). It was concluded, from the empirical findings, that today's companies work toward increasing the proactive activities to improve product and service quality. Proactive activities can be seen as quality costs and not poor quality costs. With this as argument, prevention costs were not considered when developing the tool, see figure 4.5. From the empirical findings it was concluded that the waste category, included in the synthesis of CoPQ classification, can be included into internal and external failure cost. In line with this, waste is excluded as a separate category, see figure 4.5. The redesigned classification of CoPQ has been the basis for the development of a tool to identify and quantify CoPQ.

Synthesis of CoPQ classification

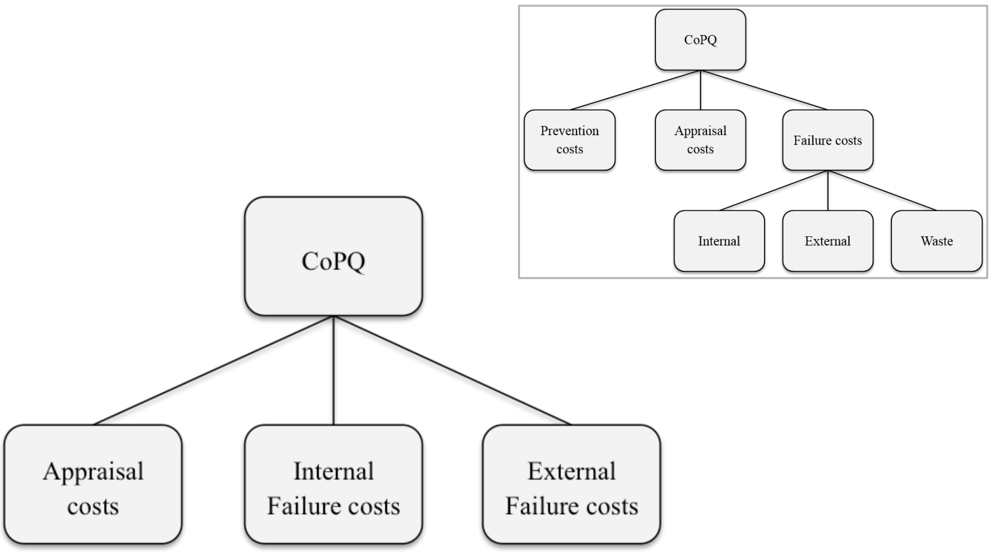

Figure 4.5 - Redesigned classification of CoPQ.

Harrington (1987) classifies CoPQ into direct and indirect costs. Direct costs can be defined as costs that arise due to errors in the processes. A direct cost occurs directly and has the characteristics to be easy to identify and quantify. It was concluded from the empirical study that the direct costs are often well understood in the company, and these costs are the ones most frequently mentioned during the interviews. One example is scrap. It is a cost parameter that usually occurs in production process and people find it easy to relate to. Obviously, direct costs are easier to measure and quantify, compared to indirect costs, since these costs often are visible in the company's processes.

The empirical study showed that indirect costs are often less understood. Harrington (1999) discusses indirect costs in four major categories: customer-incurred costs, customer dissatisfaction costs, loss-of-reputation costs and lost-opportunity costs. Unsatisfied customer was mentioned during the interviews as an indirect cost that is hard to identify and measure. Moreover, Dahlgaard et al. (1998) classify CoPQ into visible and invisible costs. One interviewee explained CoPQ as all costs that arise in a company, both visible and invisible, and occur due to poor costs. Several costs, found in the literature study as well as the empirical study, are hard to measure such as communication, personal motivation and information sharing. To enable identification of these cost parameters one part of the tool will be conducted as a survey. The survey will help the company to get an understanding about how these parameters are perceived by the respondents of the survey.

From the empirical findings it was found that managers are often interested in knowing where in the company CoPQ arise. By knowing this, it could be easier to decrease CoPQ. Since different functions experience different CoPQ, there is a need of dividing CoPQ per function. First it was seen that identification of CoPQ within R&D is challenging, mainly because problems often arise in later phases of a product's supply chain. For instance, it is hard to decide whether a delay in a product development process is waste or not. Second, in production it is usually easier to find direct CoPQ that occur during the production processes e.g. scrap during production or rework due to scrap. Third, after sale is the function where costs become visual, e.g. customer claims, which are often presented in deviation reports. In all the three functions, it might be challenging to identify and quantify CoPQ if data does not exist. It is important to remember, when dividing CoPQ into functions, that cost might occur in more than one function such as absence due to illness, lack of motivation and low work. A common CoPQ category would be beneficial to have in the tool.

Since every company is unique, measurements of CoPQ must be adapted to each company's needs. In line with Sörqvist (2001), a company must determine which CoPQ that affect the business operations most. However, many times a company does not have the knowledge about these CoPQ and it would therefore be beneficial to start measuring a few general CoPQ that often occur in companies, such as scrap or warranty. This will enhance the understanding about CoPQ for the company and could be a basis for further decisions of which CoPQ to identify. Another way to start the identification process is to investigate what kind of failure data that already exist in the business system. Both current literature and the empirical findings emphasize the importance of measuring CoPQ and build knowledge about what costs that have the biggest influence on the company. Measurement results will enhance the trustworthiness in decision-making process and can be used to get everyone committed to changes. Despite this, too much measurement has its drawbacks. First, there are companies that put more efforts in measuring CoPQ compared to solving the actual problems. Second, too much measurement creates lots of results which have to be analyzed in order to create value for the company. This requires resources in terms of staff, time and money. Hence, to create a balance between measurements and problem-solving, it is beneficial to connect CoPQ to the process in which it arises.

Independent of cost type, the ways to measure need to be well developed and carefully prepared. Each way has its own benefits and should be chosen in order to fit the selected CoPQ. Current literature suggests starting create a process map to visualize CoPQ in relation to a process, to then continue measuring few critical CoPQ in a simple measurement system to enable continuous data (Sörqvist, 2001). In line with this, the empirical findings show that a combination of measurement alternatives was beneficial in order to identify a wider range of CoPQ. A process map requires cross-functional competences in the company, which engages employees from different functions. Already in this step the entire organization is being involved in the identification process of CoPQ. From the empirical findings, it is found that individuals have different opinions whether a formal measurement system is preferable or not. Some individuals experienced measurement system as resource consuming compared with the value it created. Others saw measurement system as necessary in order to get continuous data and facilitate the analyze process. Sörqvist (2001) stresses the importance of having broad knowledge and strong motivation among the employees when using a measurement system. From both current literature and empirical findings, measurement of CoPQ is discussed as hard to manage. Obviously, companies need the right competences and resources to be able to take advantage of the measurements. Furthermore, establishing a sustainable way of working with CoPQ, where all people involved are committed and that meets company needs, is beneficial independent on the choice of measurements. This means that it is important to have a structured way of working with measurements and have knowledge about the goal of measuring.

All above-mentioned measurement methods seek to find those CoPQ that affect the company most. Another way to identify CoPQ, especially the invisible cost, is to work from a defined problem, similar to the Six Sigma concept. This identification procedure requires more time compared to the other measurement methods since it is often carried out by a group of employees that meet continuously (Schroeder et al., 2008). From the interviews it was concluded, that working from a problem would probably gain understanding about several

CoPQ. Due to the investigation's time limit, working from a problem would require longer time than two days.

4.3.3 The tool to identify and quantify Cost of Poor Quality

The purpose of this master thesis was to develop a tool for identification and quantification of CoPQ within the three functions R&D, production and after sale. Two investigators should be able to use the tool for investigation in a company during two or three days. The tool requires that measurements of cost parameters already exist in the investigated company, since there will be no time to start new measurements. Five main parts classify the tool; *research and development, production, after sale, common CoPQ* and *soft factors of CoPQ*, see figure 4.6.

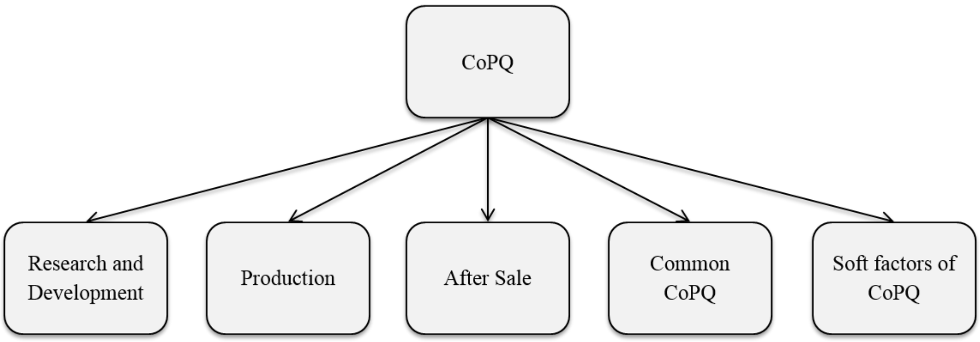

Figure 4.6 - The classification of CoPQ in the tool.

Each part includes a number of clusters, which in turn includes a number of cost parameters suggested to be identified. Figure 4.7 visualize a cluster including three cost parameters. Moreover, a feature is that each cost parameter has an explanation of its content and a suggestion on how it can be measured, see appendix IV. There are going to be situations where the investigators are not completely sure if the cost is correct quantified. Therefore, an estimation scale is added to point out how much the cost is estimated, where 1 represents low estimation and 3 represents high estimation. By calculate and filling in numbers for respective cost parameter, the investigated company's CoPQ can be presented.

Cluster	Cost parameters	Tips how to measure/quantify	Cost	Unit	Total cost per parameter	Est. 1	Est. 2	Est. 3
Scrap	Incoming material/component	(SEK*weight), (SEK*m2), (SEK*number of components)	3000,00	SEK	3000,00		x	
	In production process	(SEK*weight), (SEK*m2), (SEK*number of components)	300,00	SEK	300,00	x		
		(Labor cost*hours for operation)	4000,00	SEK	4000,00	x		
		(operating cost*h)	3500,00	SEK	3500,00		x	
	Final product	(SEK*weight), (SEK*m2), (SEK*number of product)	500,00	SEK	500,00	x		
		(Labor cost*hours for operation)	4000,00	SEK	4000,00			x
		(operating cost*h)	4500,00	SEK	4500,00		x	
	Additional cost		-					
Total Scrap			**19800,00**	**SEK**	**19800,00**	3	3	1

Figure 4.7 - Selection from the tool, visualizing scrap cluster with respective cost parameters in production function. The numbers are fictional.

Independent of which part of the tool the investigator works with, the structure is similar. One example is that the clusters follow a similar order, for example, the cluster personnel is the last cluster in each part. Moreover, each cluster includes a parameter called additional cost, which gives the investigator the possibility to add parameters to the cluster. To facilitate the identification process the tool's parts are designed as checklists. The investigator can control what CoPQ are identified and what remains. Since the tool is supposed to be applicable in different contexts, the tool is designed in Microsoft Excel which is a software commonly used in organizations. Microsoft Excel also provides the flexibility to add cost parameters or functions. A selection from the tool presenting an entire function's CoPQ can be seen in appendix V.

Below, each part will be described in detail with motivation to why clusters and parameters are included and others are excluded. Quantification methods are also described in this section. How CoPQ should be presented to top management and the investigation procedure are further described.

4.3.3.1 Research and Development

The first part of the tool concerns CoPQ in R&D. This part includes three different clusters; *Rework, Delay* and *Personnel*, see figure 4.8.

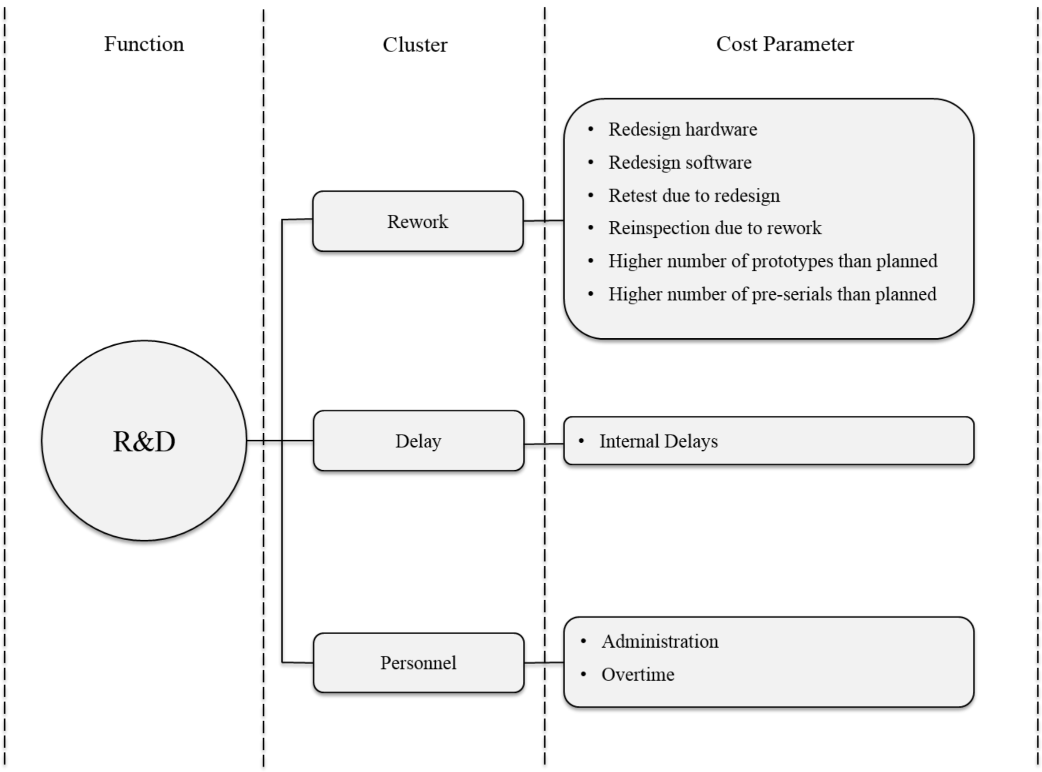

Figure 4.8 - R&D function with CoPQ clusters and respective cost parameters.

From the empirical findings, it is challenging to identify and measure CoPQ in the R&D function. CoPQ is usually connected to a problem occurring in a process such as production downtime or supplier delays. This is not possible to the same extend in R&D since the product is developed and it is difficult to decide what is a problem or not. The value of a problem, in terms of money, increases with the product's value chain. However, the place where the CoPQ is discovered does not have to be the same place where the problem arose.

This means that problems occurring in R&D can be discovered and visualized in after sale. Anyhow, current literature and empirical findings discuss several CoPQ that would be possible to find in R&D such as redesign and use more prototypes than necessary (Gryna, 1999; Harrington, 1987). Most of these CoPQ can be results from poor development plans.

Rework is considered to be the most important cluster within R&D, and consists of six cost parameters. Redesign of hardware and software are typical CoPQ, but since the development process is iterative it is hard to decide whether redesign is part of the iterative process or is CoPQ. However, it is argued that it is important to include redesign in the tool, since it is a cost that seldom get attention within R&D. Labor cost is one cost type that could be beneficial to start with in order to quantify redesign. If no data is available to identify the cost parameter could be estimated by the designers. Furthermore, another CoPQ easier to identify and quantify is higher number of prototypes and pre-serials than expected. Those costs can be identified through comparing number of planned prototypes/pre-serials and number of real prototypes/pre-serials.

The second part is delay, which is defined as the time a project becomes delayed due to missed deadlines and gates. It consists of one cost parameter labeled internal delays. From both the empirical study and current literature it was concluded that delays often occurs because of poor design and poor project plan. Delays can be quantified in time, since it would be possible to measure the delayed time in relation to a gate or milestone. Even though a time is presented, it would increases the understanding about the financial perspective since saved time is equal to saved money. Further CoPQ that can contribute to longer lead-times and delays are not updated instructions and incomplete information.

Personnel is the third cluster including two cost parameters, administration and overtime. Administration cost concerns non-value adding activities such as changing passwords, but can also include cost for unnecessary software licenses. Obviously, all overtime is not included as CoPQ, but when unplanned overtime occurs because of e.g. delays it becomes CoPQ. The literature sees education and training as CoPQ. However, the empirical study showed that it is a preventive activity to have education and is therefore excluded from this cluster.

The first draft of the tool included four additional clusters labeled test, inspection, scrap and stock. A test cluster was not considered as important to include, since test was discussed during the empirical study as a critical value-adding activity. Moreover, retest is part of the cluster called rework where it is visualized. According to Feigenbaum (1991) inspection is considered as an appraisal cost included in CoPQ. The empirical study, on the other hand, saw inspection as necessary to not sell damaged products. Therefore it was concluded that inspection is seen as CoPQ only when it occurs due to rework. Hence, inspection was removed as an own cluster, but to compensate a cost parameter called *reinspection due to rework* was included in the rework cluster. Scrap in R&D occurs mostly due to unplanned prototypes and pre-serials. This is why scrap was excluded as a cluster and included in rework. Furthermore, the empirical study did not consider stock as a critical CoPQ within R&D, and was therefore excluded in the tool.

4.3.3.2 Production

The second part in the tool is the production function. It consists of seven clusters; *Scrap, Rework, Production equipment, Inspection, Stock, Personnel* and *Others*, see figure 4.9.

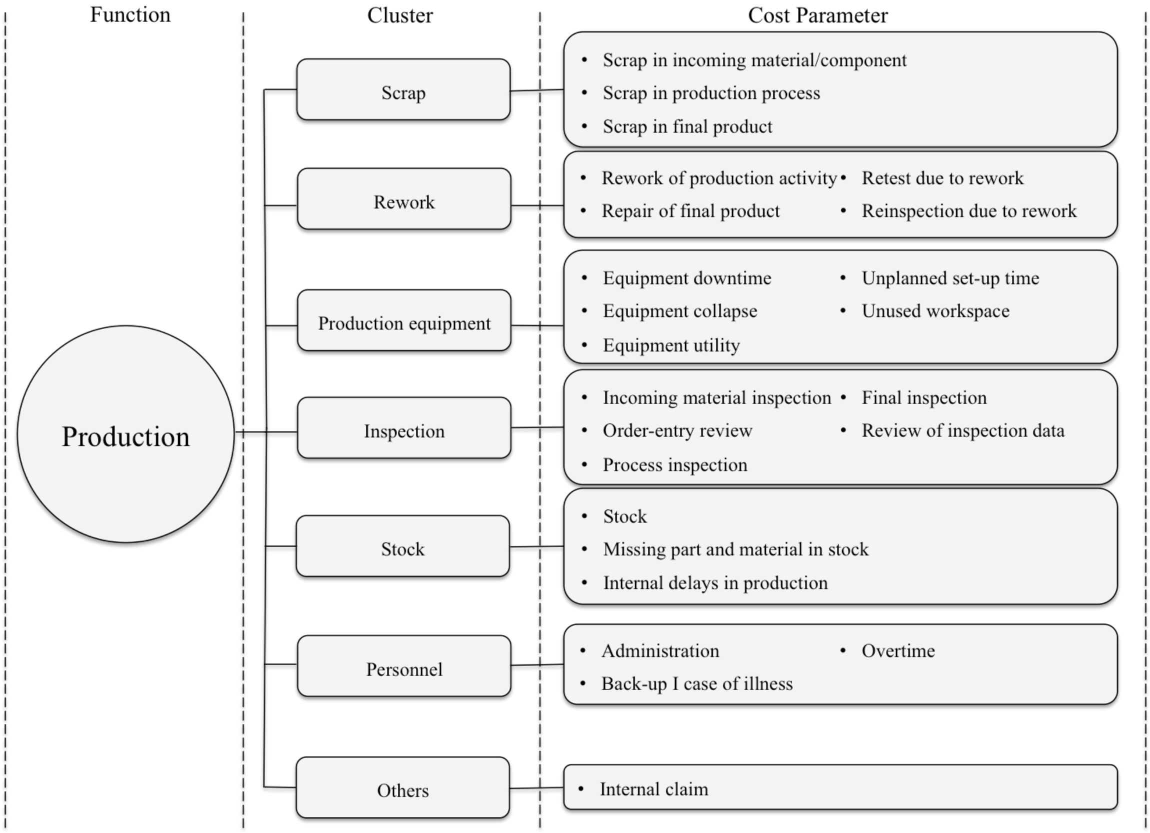

Figure 4.9 – Production function with CoPQ clusters and respective cost parameters.

Scrap was the most frequently mentioned cost in the empirical study. It is a cost the interviewees often referred to as CoPQ and is usually easy to understand. Moreover, one of Lean's seven wastes discusses defected products and scrap (Nicholas, 2011). Since both the empirical findings and the literature study highlights the cost, this cost is seen as important and is the first cluster in the production function. Since managers often are interested in understanding where in the company the CoPQ arise, this cluster is divided into three cost parameters. These are scrap of incoming material/component, in production process and of final products.

Scrap of incoming material/component can be quantified as a material cost, since no value has been added to the material/component. When calculating scrap in the production process and scrap of final products it is important to consider all value-added activities, in addition to material cost, that have been added to the products, e.g. labor and production costs.

Cluster number two in the production function is rework. Rework includes rework of production activity, repair of final product, retest and reinspection due to rework. In contrast to R&D, it is easier to identify rework in the production function. On the other hand, it can be difficult to measure rework since it occurs due to many reasons. Since the tool should be used during two or three days, there is no time to identify and quantify all costs that arise due to rework. Therefore, rework is measured as material cost, labor cost and production cost. The case company thinks they have a lot of rework, but lack of measurements make it challenging to quantify it. Further, most of the rework in the case company contributes towards scrap. In this case, the rework results in a new product. In other cases, there might just be need of adjustments. According to the Lean philosophy, *waste from producing defects* is one of the seven wastes (Nicholas, 2011). According to the Lean philosophy, all scrapped and defected products that need to be reworked result in extra resources.

Production equipment is cluster number three that consists of five cost parameters, equipment downtime, equipment collapse, equipment utility, unplanned set-up time and unused workspace. Equipment downtimes are the most common issue in the case company. However, the downtimes are not seen as a big problem in the case company even though it occurs frequently. The reason is that the company has other machines that can be used as substitute. This shows that the equipment utilization is not maximized; due to the case company's wish of being flexible. It is considered important to highlight the equipment utility. Even though the case company wants to be flexible, the profit could have been higher if the utilization was higher. Overall equipment effectiveness (OEE) can be used to quantify equipment utilization, where OEE is calculated as *Good count*Ideal Cycle time/ Planned production time*.

According to the interviewees, set-up time is a complicated factor. A decreased number of set-ups might result in a higher number of inventories in stock, which in Lean is considered as waste. That is why the tool uses a cost parameter called unplanned set-up time, which only quantifies unplanned set-ups. Further on, equipment collapse costs are included in the tool. The equipment collapse cost is the cost for buying new equipment and while waiting for the arrival of new equipment the time is seen as downtime. Moreover, current literature (Nicholas, 2011) sees equipment service and maintenance as waste. Based on the empirical study, equipment service and maintenance is seen as a prevention cost and therefore it is not included in the tool.

Inspection is the fourth cluster including five cost parameters. Both during the interviews and the case study, inspection was discussed back and forth. On one hand, it is necessary to ensure good products, but on the other hand, too much inspection may lead to CoPQ. According to Juran and De Feo (2010, p. 75), CoPQ is defined as *"the costs that would disappear in the organization if all failures were removed from a product, service, or process"*. With this definition in mind, inspection is seen as CoPQ and is included in the tool. Three of the cost parameters are inspection of incoming material, process inspection and final inspection. Since no company is perfect, it will always be CoPQ in one or more parameters in the inspection cluster. By visualizing inspection as CoPQ, a company gets insight about how costly inspection might be. From this, the company is able to consider whether the current inspections are necessary or not. Further, two more cost parameters are included, order entry review and review of inspection data. These parameters as well as the inspection parameters mentioned above are measured as labor cost. Labor cost means the time it takes to inspect and review, times the cost for the person/persons performing the activity.

Stock is cluster number five. This cluster includes three different parameters, stock, missing part and material in stock and internal delays in production. In the tool, stock is measured in three different ways, surplus stock, turnover rate and stock utilization of the production plant. The reason for having different ways of measuring stock is mainly because current literature and the case study contradict each other. On one hand, Lean classifies items in inventory as waste (Nicholas, 2011). On the other hand, the case company had a lot of inventories in stock because they see stock as necessary to meet customer orders. However, it is argued to be important visualizing stock when applying the tool. That is why three different ways to visualize stock is stated. If one type of measurement is not applicable in one company, another type can be used. Missed parts and material in stock, as well as internal delays in production are two other cost parameters affecting CoPQ. The staff and equipment waiting time that occurs when parts or material is missed can be one way to quantify this CoPQ. Another way to quantify is to visualize how many products the company loses to sell during this time.

Personnel is cluster number six including the same cost parameters as the R&D function, administration and overtime. Additionally, one parameter called backup in case of illness is added. The reason for including this cost is because the production-function often needs to have backups, since the production is always running. Backup is not as critical in R&D, since the work can often be done afterwards and not directly. Education and training is excluded, by the same reason as explained in the R&D function, since it is seen as a prevention cost.

The last and seventh cluster considers other CoPQ, including one cost parameter called internal claim. According to the case company, internal claims are important to consider and work with constantly. The case company means that since they started to discuss internal claims throughout the organization, they have seen improvements in the production processes. This is one example of why it is important to visualize this cost.

4.3.3.3 After Sale

The third part of the tool consider the after sale function. Within after sale employees talk most about CoPQ compared to the other functions. The reason is that it is the function where costs become visible. The part consists of four clusters labeled; *Product/Service failure, Customer satisfaction, Service/Repair* and *Personnel*, see figure 4.10.

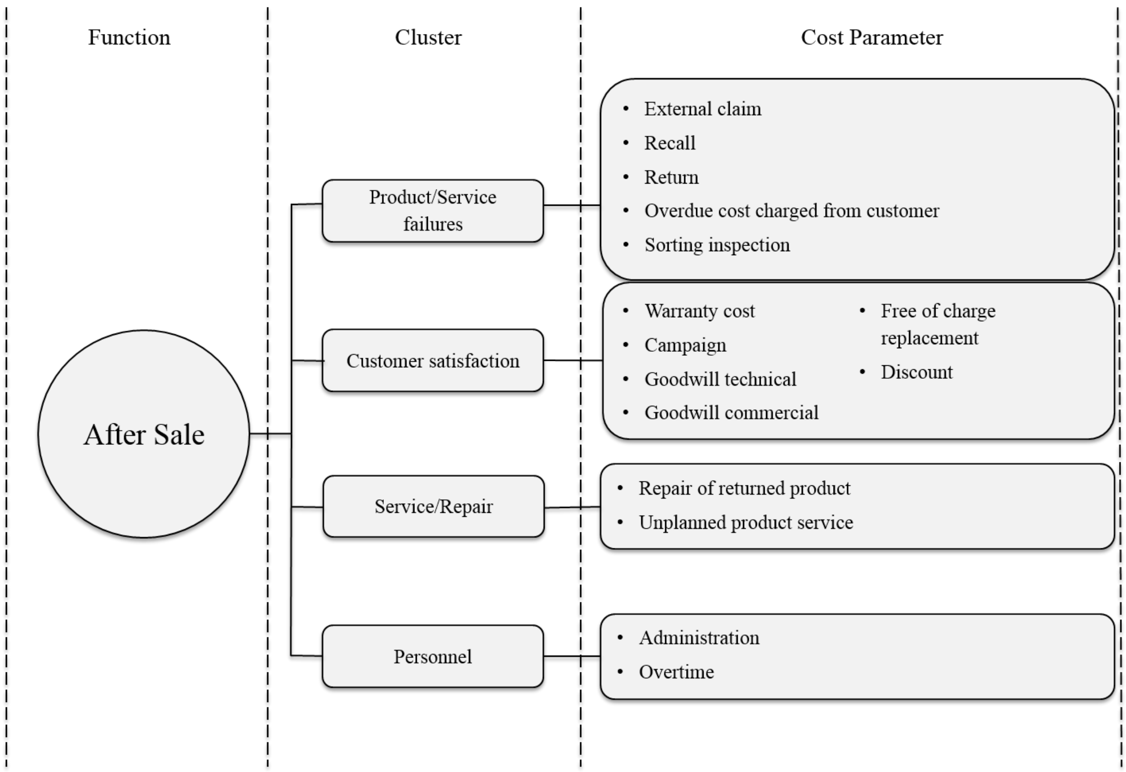

Figure 4.10 - After sale function with CoPQ clusters and respective cost parameters.

Product/service failure is the first cluster within after sale. Five cost parameters are included and all of them arise when a failure on a product/service appear. The costs parameters within this cluster are external claim, recall, return, overdue cost charged from customer and sorting inspection. These parameters are often quantified directly in money and from the empirical findings it was concluded that companies usually have knowledge about these costs. Therefore, it is easy to get access to required data.

According to the case company, external claims are a common cost. The empirical study highlighted the importance to investigate what a company includes in their claim cost. For instance, the case company included four cost parameters in their external claim cost that are stated in the tool as individual cost parameters. When such a situation occur, it is important to be observant and not include the costs in both the claim cost and as individual costs.

An additional cost parameter is sorting inspection, which is measured as labor cost. The sorting activity can be done in-house and at customer field, but is seen as CoPQ in both situations. Moreover, Nicholas (2011) discusses sorting activity as waste, since it is required due to producing defects. In the first draft of the tool, scraped products by customer was a part of the product/service failure cluster. However, the tool does not include scrap by customer with the argument that the products have already been paid. Scrapped products by customer will result in other CoPQ since the customer will be unsatisfied such as free of charge replacement and goodwill.

Customer satisfaction is cluster number two in the after sale function. Harrington (1999) includes customer-dissatisfaction in his indirect costs since it is important to consider when identifying CoPQ. Six cost parameters are included in the cluster, these are: warranty cost, campaign, technical goodwill, commercial goodwill, free of charge replacement and discount. The stated cost parameters aim to satisfy customers while problems are being solved. According to the interviews, warranty is a major cost in companies today, which sometimes is higher than the design cost. It is argued to be a connection between high warranty cost and bad communication. If the communication between functions is poor, it is hard to design products that satisfy the customer and meet their requirements.

When investigating warranty, it might be interesting to measure the lead-time until the problem is solved. The longer time it takes, the more costly the warranty becomes. The empirical study showed the importance of having correct information between the functions and the customers.

The third cluster is service/repair including two parameters, repair of returned product and unplanned product service and maintenance. Repair of returned products may include the cost of new material, labor cost and production cost to run the repair process. From the interviews, repair-repair was mentioned as CoPQ meaning to do repairs more than once. Furthermore, the literature stated maintenance service as a CoPQ. However, some maintenance services are planned in advance and the costs are already included in the product. Therefore the tool does only include unplanned and unexpected product maintenance service and not all type of services and maintenance.

Personnel is the fourth cluster including the same parameters, administration and overtime, as the R&D function. Education is excluded from the cluster as it is seen as a prevention cost.

4.3.3.4 Common Cost of Poor Quality

As previously explained, some cost parameters are difficult to relate to one of the three functions. Often, they are handled by another part of the company or include more than one function. These parameters are stated in the part common CoPQ, which includes five cost parameters; lead-time in quality issues, problem-solving resources, failure analysis, expediting costs and person injury, see figure 4.11.

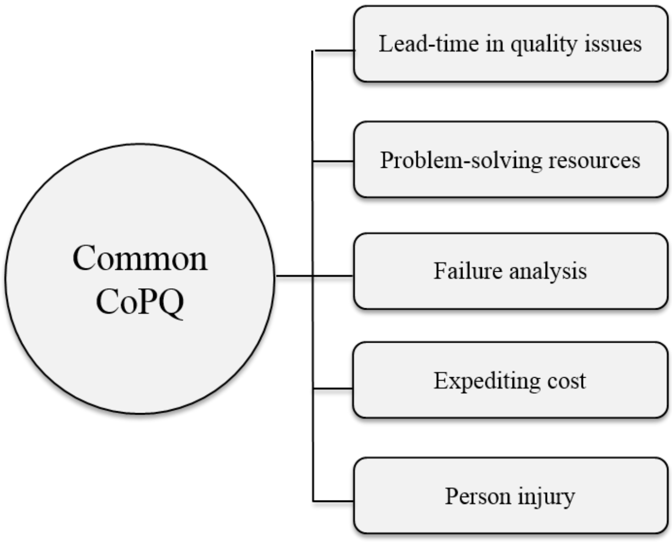

Figure 4.11 - Cost parameters included in common CoPQ.

The first parameter, lead-time in quality issues can be measured as the time period from reported claim until the problem is solved. According to (Sörqvist, 2013), lead-time can be used to visualize waste. By measuring lead-time, the company can realize how much money they can save by working more effective with quality.

Problem-solving resources can be calculated by knowing how much time that has been dedicated a problem. The more time and the more people involved in the problem-solving process, the more expensive the problem becomes. Similar to problem-solving resources is the cost parameter labeled failure analysis, which can be calculated by knowing the time to search for failures.

Moreover, expediting costs can arise due to many different reasons, e.g. express freight due to delayed products or night shifts because of increased workload. Found in the case study, these costs can be high and costly. Person injury is the last common CoPQ parameter. This costs includes sickness compensation due to injuries from work.

4.3.3.5 Soft factors of Cost of Poor Quality

As already discussed, there are cost parameters within CoPQ that are difficult to measure, particularly if they are indirect or hidden. For example, Harrington (1999) defines indirect costs as costs that are not directly measurable. However, the authors of this master thesis found it important to highlight these cost parameters in the tool since it is important to present the whole picture of CoPQ. These parameters are called soft factors and occur in the entire organization. Due to the time limitations, there will be no time to start measure these soft factors. According to Krishnan (2006), there needs to be a measurement system to be able to capture hidden costs. However, to have the possibility to highlight these soft factors within the time limitation, a survey will be used, see appendix VI. The survey does not have the ability to quantify CoPQ into money, but it will indicate where CoPQ exists and how the company perceives these factors.

The survey is supposed to be sent to the investigated company before starting the investigation days. People working within the functions concerned will be the respondents of the survey, which then will be analyzed by the investigators. It is preferably to adjust the survey to the investigated company to increase the possibility to get valuable results. For instance, by deciding whether the survey will be filled out online or on paper.

The survey includes 17 questions divided into four categories. These categories consider information, resources, problem-solving and person. Each question represents one CoPQ and has five different answer alternatives, where the respondent can choose which alternative that matches his/her opinion best, see figure 4.12.

Information	Always	Often	Some-times	Seldom	Never
Do you consider that you have the information you need to perform your work?	o	o	o	o	o
Do you consider that you have the documentation you need to perform your work?	o	o	o	o	o
Do you consider that the communication between your department and other departments work well?	o	o	o	o	o
Do you consider that you get the feedback you need to perform your work?	o	o	o	o	o
Do you consider the instructions and/or documentation related to your work is up to date?	o	o	o	o	o
Do you follow instructions given?	o	o	o	o	o

Figure 4.12 - Information category with answer alternatives.

4.3.3.6 Presentation of Cost of Poor Quality

Presentation of CoPQ is an important step in the investigation process. Top management gets the insights about what cost parameters affect the business operations most and what cost parameters that are not identified. The investigators have to adapt the presentation to the identified CoPQ to increase value for the company. An ideal situation would be when all identified CoPQ are quantified in money. However, this is not often the reality. The investigators must find complementary ways to quantify CoPQ and convert them into money or find other valuable ways to quantify CoPQ such as failure rate.

The presentation of CoPQ needs to be easy to understand and include figures. As discussed by quality specialists, the top management is interested of the total view of CoPQ. Therefore, the hard CoPQ for all functions and respective clusters can be presented in a waterfall diagram, see figure 4.13. This diagram enhances the understanding about where in the organization the hard CoPQ are highest, in this case within production.

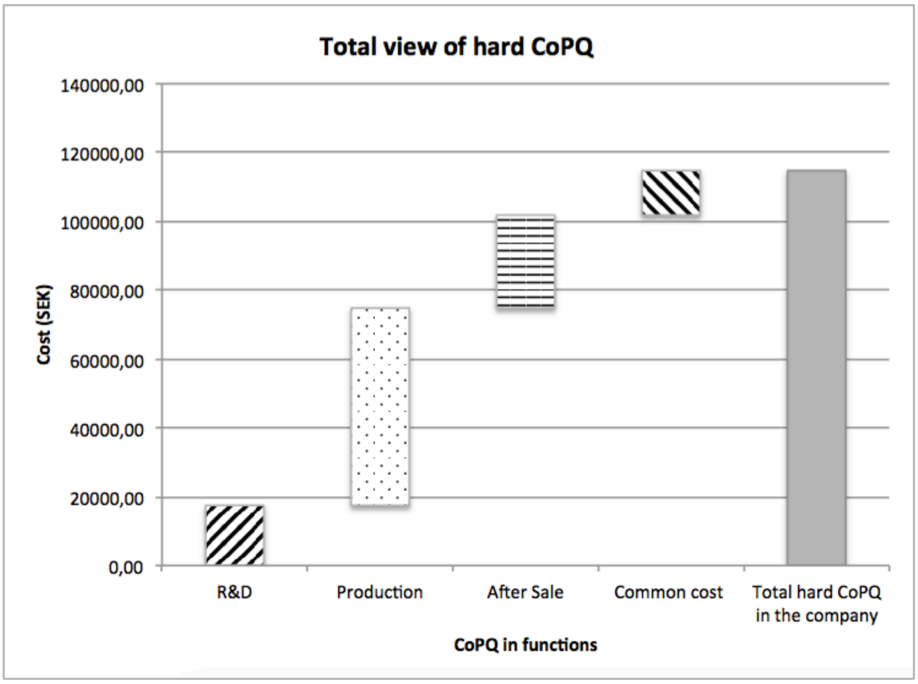

Figure 4.13 - Waterfall diagram presents the different functions in relation to total CoPQ. The numbers are fictive.

To present cost parameters in each cluster, affecting the total CoPQ in each function, bar charts are beneficial. Figure 4.14 visualizes how cost parameters included in scrap cluster can be disposed. In this case, scrap of final products are the most expensive.

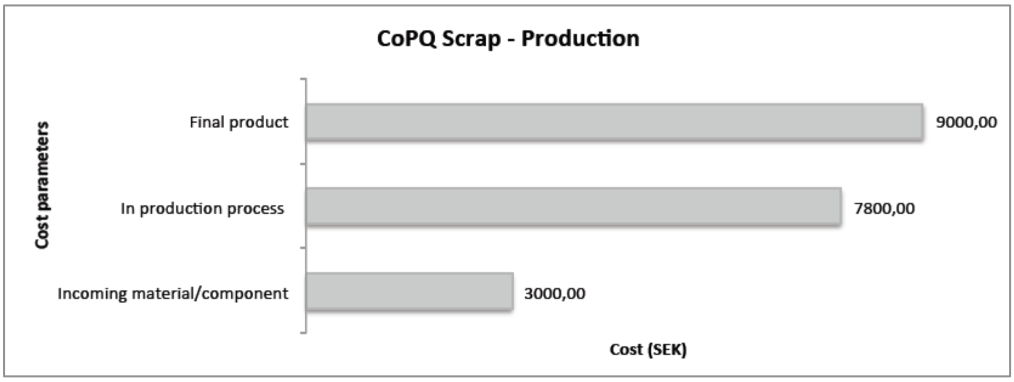

Figure 4.14 - Bar chart presents scrap cluster with respective cost parameters. The numbers are fictive.

From both the waterfall diagram and the bar chart it is easy to identify the most critical CoPQ. However, figure 4.13 and 4.14 are visualizing the ideal case when all identified cost parameters are quantified in money. If it does not exist data about one cost parameter, the bar chart will not present this cost. However, if data exist in another format than money, it is crucial to present it besides the tool since it could be valuable for the company.

The soft factors measured through the survey are presented in bar charts, similar to above-mentioned figures, to visualize the distribution of answers. It is recommended to mark interesting and distinctive results from the survey to make it useful for the company.

All the presented material could facilitate future improvement projects within the company.

4.3.4 Step by Step guide tool

To be able to perform the investigation the work procedures have to be well prepared and planned. A step-by-step guide for the investigation has been developed and is visualized in figure 4.15. This guide should be followed to identify CoPQ in the three functions.

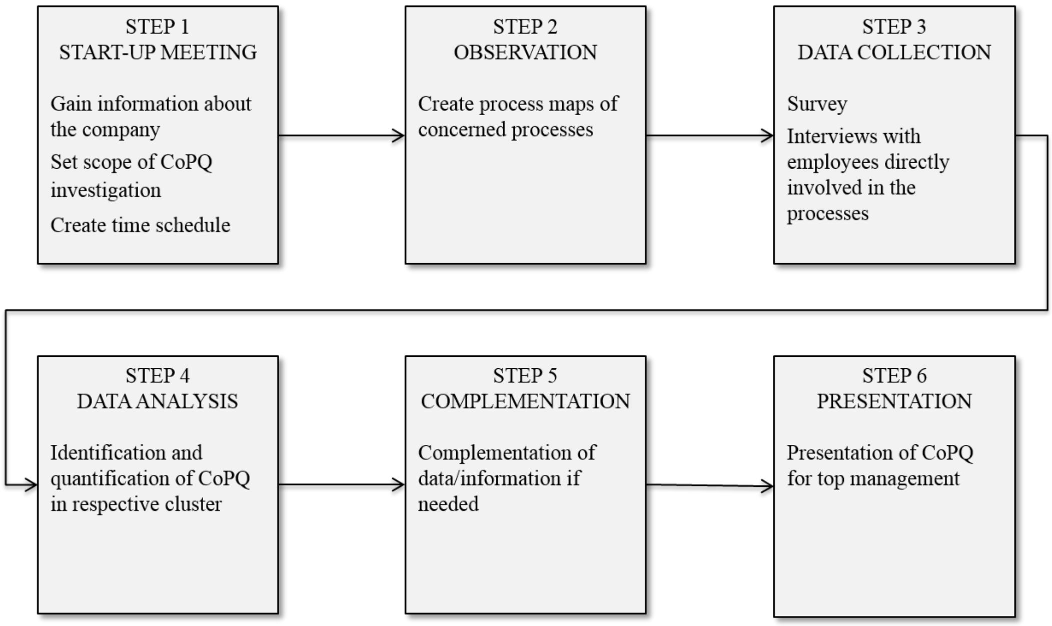

Figure 4.15 - Step-by-step guide for identification and quantification of CoPQ.

Since the investigation aims to be conducted during two or three days it is important that the investigators and the investigated company start with a common understanding about CoPQ. The investigators need to collect information about the company, what problem the company experiences most critical and examine on what needs that drive the investigation. During a start-up meeting these objectives are discussed, and the meeting preferable takes place one month before the investigation starts. In line with Bergman and Klefsjö (2010), top management commitment and involve right people in the investigation are essential factors to increase the ability to achieve best results. Due to the time limitations, it is beneficial to create a time schedule describing when people are available for interviews.

Step number two aims to gain an overview of the processes the investigation concerns. Observations of the processes will enable to create process maps. These maps will give the investigators hints about what activities in the processes that are most critical. Already in this step, CoPQ can be identified.

Data collection is a central part of the tool. The data will be basis for the quantification of CoPQ. The survey would preferable be send out to the people concerned in connection to the start-up meeting. Interviews will continuously be held during the first two days and it is important to be prepared with questions adapted to each interviewee's CoPQ area. The cost parameters determined in the tool can be used as a checklist during the investigation. This increases confidence and control for the investigators. When the investigators find the data collected enough, it is time to review the CoPQ.

Finally, when all CoPQ are identified and calculated the results can be presented for the top management. Even though data is missed in clusters, this will be valuable results to visualize for the top and can be used for improvement suggestions.

4.4 Applying the tool

To verify and gain practical experiences about the tool and its performance, the authors of this master thesis tested the tool in the same company as the case study was performed in. The company is anonymous and all presented numbers are fictive. The test was aimed to perform in the same manner as if it was a real scenario, see figure 4.15. Before the application, employees from the consultancy firm agreed upon the content and layout of the tool.

The investigation lasted for two days and considered the production and after sale functions. Since the case company does not have a separate R&D function, the investigation firstly included the process planning department. However, in agreement with the investigated company it was concluded to not consider this department in the investigation. A review of the tool is showed in figure 4.16, where the tool's strengths and challenges are presented.

STRENGTHS

- The division by functions
- Flexibility
- Estimation scale
- Checklist
- The link between completion of cost parameters and presentation feature
- Two investigators

CHALLENGES

- Hard to use the tool without measurements
- The tool lacks alternative quantification methods
- Beneficial with previous experience of CoPQ
- Need broad understanding about the investigated company
- Preferable with longer investigation period
- The tool requires right people with right information
- Wider range of respondents of the survey
- Challenging to draw conclusions from survey results

Figure 4.16 - Review of strengths and challenges from applying the tool.

The structure of the tool, which considers each function separately and compiles all CoPQ to a presentation sheet, is a strength. There is a flexibility to adapt the tool to each specific company's needs. To enhance reliability towards top management the estimation scale of the cost parameters is another strength. Furthermore, the checklists within each function describing all CoPQ cluster facilitated the identification process. Another experienced strength with the tool is when starting fill out the tool, the CoPQ is directly presented in the presentation sheet. It visualizes where in the organization the CoPQ are highest but also where CoPQ is missed. As can be seen in figure 4.17 and 4.18, the investigated company had good knowledge about CoPQ within after sale.

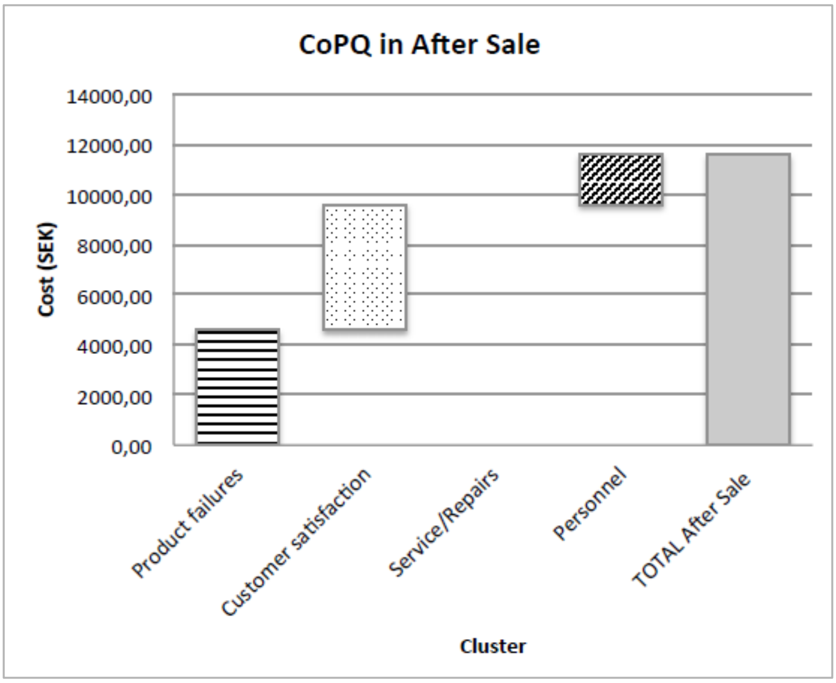

Figure 4.17 - Presentation of CoPQ in After Sale. The numbers are fictive.

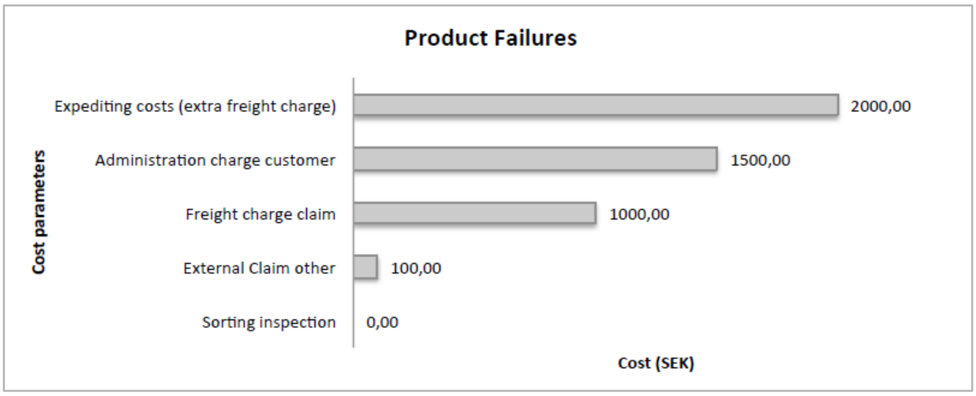

Figure 4.18 - Presentation of cost parameters within the product failure cluster. The numbers are fictive.

When identifying CoPQ it is crucial to verify the reliability of data with person responsible. From the test trial it was concluded that the *administration charge customer* was too low, and this knowledge was a valuable result for the company.

During the case study it seemed that the company had ideas how to identify CoPQ in production. However, from the test trial it was concluded that the company did not have enough data about cost parameters within the production, which made the presentation of CoPQ complicated. As consequence, it became challenging to present an overview of total CoPQ in the company. Without measurements of CoPQ the tool is challenging to use. Unfortunately, there was no time to start new measurements of processes. Of course, to visualize the top management that the company has inadequate knowledge about CoPQ was a valuable result. The top management realized they were in need of starting work with CoPQ throughout the organization. Also they were interested in starting measure few CoPQ to increase the knowledge about these sizes.

In combination of the authors' of the master thesis insufficient practical experience of CoPQ and lack of alternative quantification methods, it might have contributed to shortage of CoPQ in production. In this situation it was important to focus on the most critical CoPQ where the process map became supportive. During the observation of the processes the most critical problems could be identified, such as scrap, rework and equipment downtime. These problems could then be foundation in the discussion to identify CoPQ. Despite lack of information regard several CoPQ, the tool's content seemed to be appropriate for the CoPQ investigation. It was found out that some cost parameters were seen as preventive costs such as unplanned maintenance and internal claims which both regarded production. These costs were excluded from the tool. Furthermore, it is important to ensure that cost parameters are only considering one time in the tool, since otherwise it would contribute towards misleading results.

Another challenge is that the tool requires the right people and the right information. There could be many people involved to find one CoPQ. For instance rework of production process, which includes material costs, labor cost and production operating cost. The investigators experienced shortage of time during the test trial, which also could be a reason for missed CoPQ.

The soft factors of CoPQ are identified through a survey. Figure 4.19 is visualizing the results of one cluster considering person. As can be seen in the figure, the answers for each question are widely distributed.

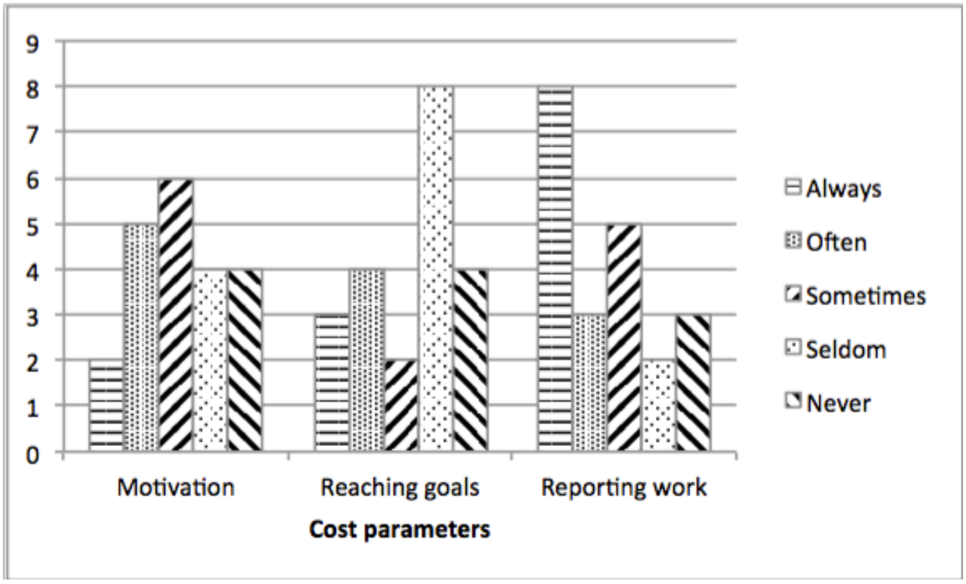

Figure 4.19 - Answers considering person. The numbers are fictive.

From this result, it was challenging to draw a common conclusion about each CoPQ. The survey was sent to operators in the production and the results might be different if the range of respondents was wider. In addition, the respondents found it difficult to choose between the predetermined answers alternatives, and suggested more alternatives.

5 Discussion

According to Sörqvist (2001), there is no existing tool to identify and quantify CoPQ. The author means that it is challenging to generalize the quantification process when CoPQ occur differently within different companies. From this master thesis it has been seen that most CoPQ classifications are based upon the PAF-model, which divides CoPQ into prevention costs, appraisal costs and failure costs. The PAF-model was first introduced by Feigenbaum (1991), and lacks in information how to quantify the cost parameters and where those arise. In order to decrease CoPQ in a company, it has been concluded from this master thesis that it is beneficial to connect each CoPQ to where it arises. Therefore, a tool has been developed to identify and quantify CoPQ within the functions R&D, production and after sale. Furthermore, in previous research the focus has mainly been on identifying CoPQ within production (Harrington, 1999). This also means that most of the improvement suggestions concern production. However, CoPQ in production is only one part of the total CoPQ in the organization and the developed tool contributes by emphasizing the importance of considering all functions. If CoPQ is reduced in early steps of the product supply chain, CoPQ will be reduced in later phases as well. Despite this, the tool does not involve as many cost parameters within the R&D-function compared to the other two functions. The most challenging with CoPQ in R&D is to differentiate what activities are proactive and what activities lead to poor quality.

Even though Bergman and Klefsjö (2010) emphasize the usage of the term CoPQ, this master thesis found that the usage of the term CoPQ varies in companies. Mostly it depends on peoples' competences, previous experience and interest of CoPQ. It was concluded that the term CoPQ requires a common definition throughout the company before the identification and quantification process is supposed to start. Also, it is important with a common understanding about CoPQ between the investigators and the investigated company. However, to successfully implement CoPQ a common definition of CoPQ is not enough. The company is in need of employees' commitment to identify CoPQ. In general, people are afraid of new concepts, which means the implementation could require changes in people's mindset towards quality. According to Foster and Whittle (1990), it is challenging to change the quality mindset. Obviously, people's mindsets are hard to change in two days, and it is important to remember that there could be resistance among employees.

It has been concluded that companies have different possibilities to identify and quantify CoPQ, which could be connected to each company's maturity level. The more mature organization and the more knowledge about the organization's processes, the more CoPQ can be identified and quantified. This emphasizes the importance to adapt the investigation of CoPQ to each company's needs. Furthermore, instead of using the term CoPQ it has been seen from the empirical findings that some companies use key performance indicators (KPIs). There are similarities between the two concepts. KPIs measure performance of activities and evaluate an organization's success and CoPQ visualizes costs generated from poor quality activities. However, KPIs should not be used as a substitute for CoPQ rather as a complement. KPIs can be used in the identification process of CoPQ since KPIs indicate about what poor performance activities there are in the company.

It has been concluded that it is difficult to identify and quantify CoPQ in every situations, e.g. due to lack of measurements. Even when it is impossible to quantify costs into money, it would be valuable to include these costs in the tool when investigating a company. Another alternative would be to exclude the costs from the tool. Stated by Krishnan (2006), lack of measurements can contribute towards losses of crucial information to business operations.

That is why it is argued to highlight the costs even though it is impossible to quantify it in money. Otherwise, the company would think that they are having lower CoPQ then they actually have. It is possible to quantify CoPQ in relation to other terms such as revenue and turnover. However, the tool lack in function to make this connection successfully. It only visualizes which cost parameters that are not quantified in money, but it does not present these costs. Therefore, the investigators have to present these cost manually. In line with the increased usage of the tool, the experience about how to visualize and present CoPQ independent on unit will increase.

According to Sörqvist (2001), previous research means it is hard to make a generalization for what cost parameters that should be included in the tool. However, the tool contributes with a flexible design, where the user can change and work with the tool in a way that is suitable for the investigated company's situation. To further facilitate the usage of the tool, it is designed to be generalizable and to follow same steps, see figure 4.15. Stated in the literature, there is no existing model that can be used to identify and quantify CoPQ for all types of organization (Sörqvist, 2001). That is why the intention is to contribute with a tool that should be applicable in small and medium sized enterprises, independent on industry and branch. To increase the easiness of using the tool, a step-by-step guide has been developed, which helps the user of the tool to apply the tool.

The consultant firm asked for a tool, which could be applied during two or three days. However, if the intention is to investigate all parts included in the tool, which are R&D, Production, After Sale, Common CoPQ and Soft factors, it has been concluded that it is a short period of time. The case study showed that it is impossible to analyze a company during two days, if the company wants a comprehensive investigation including all parts of the tool. If the company would have better structured data or was asked for a smaller and not that detailed investigation, two or three days would be suitable.

According to Sörqvist (1997) and Oakland (2003) companies need to be aware of CoPQ in order to continuously improve their quality. By identifying CoPQ, companies get an understanding about costs and can start to reduce them. It was found that there are several ways of working with quality improvements. One example is to work from a defined problem. Working from a problem may enhance the identification of CoPQ, since the investigator knows what to look for. However, the tool's intention is to give a company an indication of their CoPQ. This identification and quantification of CoPQ is only one part of quality improvements, where the company identifies what costs that affect the business and where in the company those costs arise. From that, problems can be found and will be the basis for short-term and long-term improvements and new standards in the business.

The same company has been involved both in the single case study and when applying the tool. The purpose of the single case study was to gather data about CoPQ to develop the tool. Moreover, when applying the tool the purpose was to validate the investigation process of using the tool, see figure 4.15. Since the tool is intended to be generalizable, it needs to be applied and tested in other industries and in several companies. Also, to validate the usage of the tool, it would be beneficial that consultants in the consultancy firm perform CoPQ investigations. The study has been limited to the functions R&D, production and after sale. By only investigating three functions, a company does not get the full picture of their CoPQ. It would be interesting to further investigate other functions such as marketing and sales. The marketing and sales function is closely related to the customers and is interesting to investigate. Especially, since it is important to meet customer requirements in order to avoid CoPQ. A further possibility that could be experienced when applying the tool in several companies is to find the minimum of data needed to be able to perform the investigation. As already discussed, lack of data in CoPQ is valuable results for the company. However, it would be beneficial to know the minimum amount of data required to have the possibility to give the company information about their CoPQ situation.

Today, the tool includes a suggestion about how each cost parameter can be quantified. To enhance the use of the tool, it would be preferable to have more suggestions about how cost parameters can be quantified. Moreover, it is possible to develop the tool further. For example by including a part where larger calculations about cost parameters can be done and presented. Another potential improvement area is to make the estimation scale visualized when presenting the CoPQ. Today, it is a part of the tool but the estimation scale is not visualized in the presentation slide.

According to Krishnan (2006) the hidden costs in a company can be enormous. Many hidden costs go unrecognized because they are not measured or reported (Krishnan, 2006). When developing the tool, it was found easier to identify and quantify visible costs. That is why one part of the tool is based upon a survey, which quantify soft factors. The results from the survey are presented as bar charts. Today, there is no information what result should be classified as CoPQ. Therefore, it would be interesting to develop a guide of how to draw conclusions from the survey. But also to identify how the soft factors can be presented in a valuable way.

6 Conclusion

The purpose of this master thesis was to develop a tool for identification and quantification of CoPQ within the three functions Research and Development, Production and After Sale. Further, the tool should present CoPQ in a visual way for an easy overview of the organization's current situation with regards to CoPQ. The tool was developed through a single case study and interviews with quality expert and specialists.

It was concluded that individuals with different work experiences have different views of the term CoPQ and its meaning. The empirical findings showed the importance of a common understanding about CoPQ throughout the company and which cost parameters that are considered as CoPQ. Further, lack of understanding of the term could result in a lower possibility to reduce CoPQ in the company.

The PAF-model was the first classification of CoPQ which represents prevention, appraisal and failure costs. It was concluded form the empirical study to not consider prevention cost as a CoPQ and include waste in failure costs. Therefore a redesigned classification was discussed, see figure 4.5.

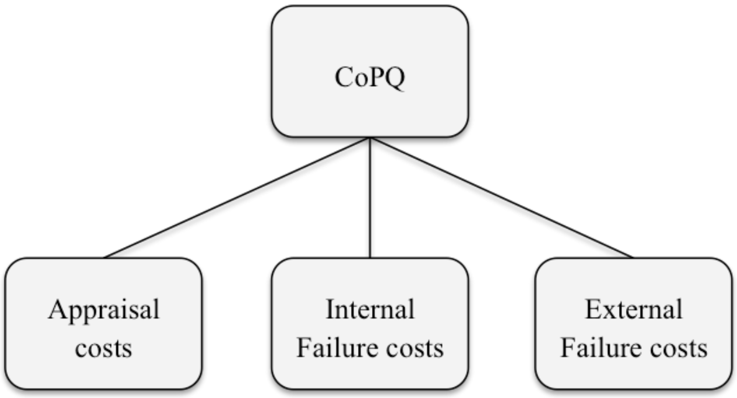

Figure 4.5 – Redesigned classification of CoPQ.

It was argued that top management is interested in knowing where in the company CoPQ arise. From the empirical findings and current literature it was seen that no tool exists for identifying CoPQ in relation to functions. That is why the authors of this master thesis have divided the cost parameters within CoPQ into three functions: R&D, production and after sale. Further, it was concluded that it is often easy to identify CoPQ in the production function, where data is available and easy to visualize. CoPQ within R&D, on the other hand, is often difficult to identify. Mainly due to the fact that the development process is an iterative process and it is difficult to decide whether it is a CoPQ or a needed activity.

The developed tool is designed in Excel and consists of five parts, Research and Development, Production, After Sale, Common CoPQ and Soft factors, see figure 4.6.

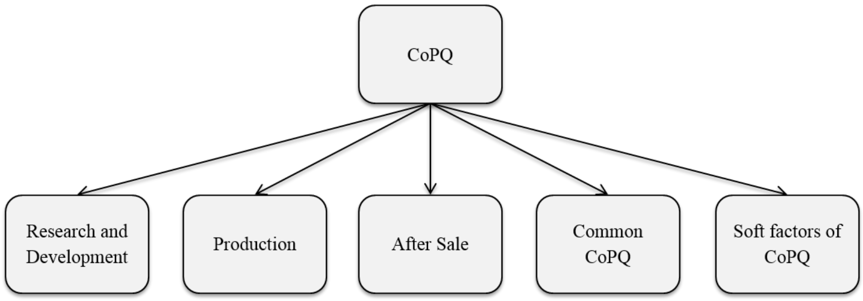

Figure 4.6 - The classification of CoPQ in the tool.

Each part of the tool seeks to quantify CoPQ. The first four parts include a number of clusters and cost parameters, with an explanation about how each cost parameter can be measured. To enhance the investigation about CoPQ, it is crucial to understand each cost parameter and why they contribute towards CoPQ. From the case study it was concluded that the case company did not measure the parameters required for the investigation. Even though it was impossible to show all parameters in money, the authors of this master thesis found it important to visualize that data were missing, but also to visualize the costs that actually were measured. Since all cost parameters cannot be measured directly, the last part of the tool is labeled soft factors. This part is based upon a survey, which can indicate where CoPQ exist and how the company perceives these factors.

In order to perform the investigation with good results, the investigators have to be well prepared. Preferably, the investigators should have previous knowledge within the quality field. A step-by-step guide has been developed with the purpose to guide the investigators through the identification process within the three functions, see figure 4.15.

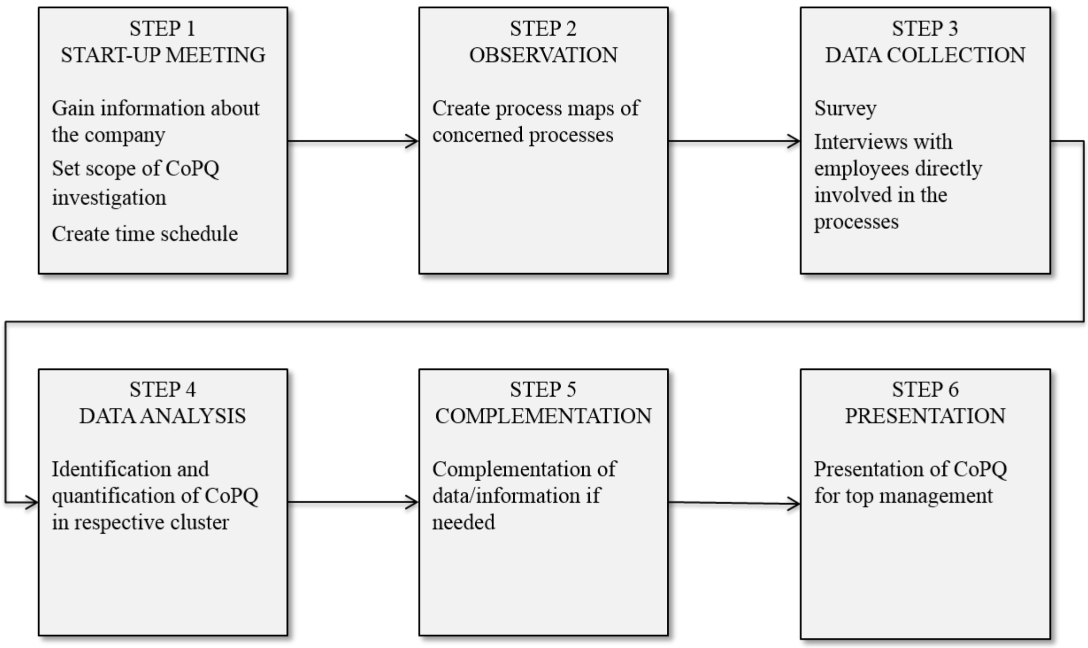

Figure 4.15 – Step-by-step guide for identification and quantification of CoPQ.

To create a common understanding about the investigation and CoPQ, a start-up meeting is argued to be necessary. The meeting will allow the investigators to understand which cost parameters that are critical and also to plan the investigation days. It is important to remember that the tool must be adapted to the investigated company. Further, the tool can be refined and improved by investigate several companies and include other departments. However, the developed tool presents the identified CoPQ, which can be used for both short- and long term improvements to decrease CoPQ. A further developed tool would give the company a more comprehensive picture of their CoPQ.

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Appendix I – Interview guides

Interview guide – Quality specialist

Introduction

1. What do you work with?
    a. What is the best with your job?
    b. What is the biggest challenge with your job?
2. What have you been working with before your current job?
    a. For how long time have you been working with quality?
    b. For how long time have you been working as a consultant?

Introduction to CoPQ

3. Why do you think companies should work with improvement projects?
4. When you are working in different companies, how do they follow-up and measure quality? Do you see any particularly challenges with follow-up and measure within your field?
5. Do you recognize CoPQ? If yes, how would you describe it?
6. How have you been in contact with CoPQ?
7. Do you think that some types of companies/functions talk more about CoPQ than others?
    a. Why?
    b. Small/Big
8. With your experience within your field X, what is your opinion regarding how companies work with CoPQ? What are the challenges?
9. What kind of costs would top management like to see? And where do you think these costs exist?

Measure CoPQ

10. What kind of CoPQ do companies measure today? What is interesting to know?
11. What is not measured, and why?
12. What do you think companies should measure?
13. Do companies have goals about how to decrease CoPQ?
14. How do companies identify those CoPQ that is impossible to measure?
15. Have you any examples of companies working with CoPQ in a good way? If so, can you describe it?

CoPQ in detail

16. If you were supposed to find the most common CoPQ in the following functions, what would you do?
    a. R&D
    b. Production
    c. After Sale
17. How is CoPQ communicated between functions?
18. Which CoPQ are most critical?
    a. Are they similar throughout the product's value-chain?

The interviewee's project today

19. Do you talk about these costs in the project you are working within?
20. If so, what do you do to identify CoPQ today?
    a. Do you use any particular tool?

Development of the tool

21. Have you ever used any method/tool for identifying CoPQ?
    a. In what kind of project?
    b. What was the result?
22. If you were supposed to use a tool for quantifying CoPQ in a company, what level of accuracy on the results would you find appropriate?
23. Do you have any ideas about how the tool can be designed?
    a. Content
    b. Layout
    c. Visualization

Interview guide – Quality expert

Introduction

1. What do you work with today?
2. How do you define CoPQ?
3. Have you any examples of companies working with CoPQ in a good way? If so, can you describe it?
4. What is the biggest challenge with CoPQ?

The historical perspective of CoPQ

5. Historically, how have companies used CoPQ?
6. In what way have Lean and Six Sigma affected CoPQ?
    a. Do they complement CoPQ?
    b. Do you know any other methods to measure CoPQ
7. We have read about many models, which have their roots in Feigenbaum's PAF-model. Which model do you sympathize with most?

Development of the tool

8. We have read that it is beneficial to identify CoPQ from supplier to customer as well as from customer to supplier. What are the pros and cons with that?
9. Sometimes it is preferable to label CoPQ with other words, e.g. production disturbance cost. What are the pros and cons of using other words?
10. Our intentions are to investigate CoPQ within R&D, production and after sale. Do you think it is difficult to classify CoPQ into these functions?
11. Do you have any other tips when developing a tool?

Measure CoPQ

12. Which are the most important cost parameters a company should identify?
13. Do you have any ideas about how to identify CoPQ in early steps of a products value chain? E.g. by using case, interviews or workshops.

14. Which interfaces between functions are most critical?
15. Do you know any measurement systems/methods, which measure more than one parameter?
16. Literature states that it is preferable to have an accuracy between -20% and +20%. Do you have any comments about this number?

Other

1. Do you know any current literature about CoPQ written in the 21th century?
2. It is important to visualize CoPQ for top management, for example by using tools. Do you know any tools for visualizing CoPQ?

Interview guide – Case company – Quality manager

Introduction

1. What do you work with today?
2. How does the organization looks like in your company? How many people do you work with?
3. What are the biggest challenges within your job?
    a. Which activities do not create value in the company's operations?
    b. Are there any problems that occur more frequent than other problems?
    c. Is there any activity that affects the process more negative than other?
4. Do the company has any quality goals?
    a. How much money do the company spend on quality?
5. Do the company use KPI:s?
    a. If so, which?
6. Do you think your company measure enough?
    a. If no, what would you like to measure?
    b. Which non-value adding activities are most important for your company?

Warranty cost

7. How high is your failure rate?
    a. How do you measure it?
8. How much are the warranty costs for product X?
9. How much are the campaign costs for product X?
10. How much goodwill do you plan for?
    a. Technical
    b. Commercial
11. How many employees work with warranty costs?
    a. Who analyzes the costs?
    b. Who administrates the costs? How much time is spent on administration?

Products back to the company

12. How often do you need to recall products?
    a. How do you calculate the recall costs?
13. How much claim costs do you have?
14. How often do customer send products back to you?
15. How are the costs for claims, recalls and returns handled?

16. How many products are scrapped by customer, and how many products are returned back to your company?
17. How much cost do you have for repairs?
    a. At customer field
    b. At workshop
    c. On returned/recalled products
18. Do you have any service function?
    a. Product service at your company
    b. Service at customer field?
    c. Customer service by phone

If failure arise

19. A customer informs you about a failure on your products, what do you do?
    a. Do you have a standardized way of working?
    b. Who reports?
    c. Who get the reports?
20. How do you investigate what is wrong?
    a. How to you investigate the root cause to the problem?
        i. Do you start a project group?
        ii. How do you estimate the time needed?
        iii. Budget
    b. How do you find a solution to the problem?
        i. Do you start a project group?
        ii. How do you estimate the time needed?
        iii. Budget

Information

21. How do you communicate with the employees?
    a. Visualized
    b. Spoken or written
    c. What do you communicate?
        i. Goals for development
        ii. Product goals
        iii. Quality goals
    d. How often do you communicate?
22. Does the communication between after sale and the other functions work well?
    a. If yes, what is communicated?
    b. If no, what is the problem?
23. If a failure arises earlier or later in the value chain, how to you get information about the failure?
24. Do you have documentation/information about every process?
    a. How often are these updated?
    b. Is data estimated?
        i. Accuracy
    c. Who reviews the documentation?
    d. Are the instructions used?
25. If information is missing, how do you make decisions?
26. How is information saved?
    a. Does everyone know how to find the information?

Inspection

27. How do you inspect in the organization?
    a. What is inspected?
    b. Where do you inspect?
        i. R&D
        ii. Production
    c. Who performs the inspection?
    d. How often?
        i. Random sample
        ii. 100% inspection
        iii. Batch

Person

28. How much do you estimate is effective work versus waiting time?
    a. Do you think you are working in an effective way?
29. How do you motivate your employees?
    a. Salary
    b. Responsibility
    c. Surveys
30. Do you provide education/training to every new employee?
    a. Educate continuously
31. Do problems arise due to lack of competence in right place?

Final

32. Do you think you are working with quality in a good way?
33. Do you want to add something?
34. Can we come back to you with more questions?

Interview guide – Case company – Production manager

Introduction

1. What do you work with today?
2. How does the production process look like within your company? How many people do you work with?
    a. Which steps does the product go through?
    b. Which steps are critical?
3. What are the biggest challenges within your job?
    a. Which activities do not create value for the company's success?
    b. Are there any problems that occur more frequent than other problems?
    c. Is there any activity that affects the process more negative than other?
4. Do your function use KPI:s?
    a. If so, which?
5. Which non-value adding activities are most important for your company?
    a. Which cost is most important for you?
6. Do you think your company measure enough?
    a. If no, what would you like to measure?

Equipment costs

7. How often does unpredictable and unplanned production stops occur? How do you measure them?
    a. Is it any process stopping more frequently than other processes?
    b. How to you make sure that your customers are not affected by the stops?
    c. What do the stops depend on?
        i. Lack of material and components
        ii. To old equipment/processes
8. Is there equipment that only operates occasionally?
9. Is the working area used in a maximal way?
    a. Unused workspace
    b. Continues flow
10. How often are set-ups needed?
    a. Does it ever occur unplanned?

Scrap

11. What is scrap depending upon?
    a. Intern delivery failure
    b. Products out of date
    c. Failure in incoming material
    d. Assembly errors
    e. Equipment disturbance
12. How much of incoming material is returned to supplier?

Resources

13. How much inventory do you have in stock for a product?
    a. Before production
    b. During production
    c. After production
14. Do you have the resources needed to meet the order for a product?
    a. Material/Components
    b. Money
    c. Information
15. How much do you estimate as effective work versus waiting time?
    a. Where does the waiting time arise?
    b. Do you think you are working in an effective way?

Person

16. How do you motivate your employees?
    a. Salary
    b. Responsibility
    c. Surveys
17. Do you provide education/training to every new employee?
    a. Continues education
18. Do problems arise due to lack of competence in right place?

Inspection

19. How do you inspect in production?
    a. What is inspected
        i. Incoming material
        ii. During production
        iii. Final inspection
    b. Where do you inspect?
    c. Who performs the inspection?
    d. How often?
        i. Random sample
        ii. 100% inspection
        iii. Batch
20. What do you do if a problem/failure arises?
    a. Do you have a standardized way of reporting?
    b. Who reports?
    c. Who get the reports?
21. How do you investigate what is wrong?
    a. How is the root cause identified?
        i. Do you have a project group?
        ii. How do you estimate the time?
        iii. Budget
    b. How do you find a solution to the problem?
        i. Do you have a project group?
        ii. How do you estimate the time
        iii. Budget
22. Do you feel that problem-solving prioritizes before new projects?

Test

23. What is tested in production?
    a. Where in the process do you have tests?
    b. Who performs the tests?
    c. Do you have tests because it is impossible to test before production?
    d. How often do you do re-tests?
24. What does your test equipment costs?

Rework

25. How much resources are registered as rework?
    a. Rework in production
    b. Re-test
    c. Adjustments of products
26. Where in the process does rework arises?

Information

27. How do you communicate production related activities with your employees?
    a. Visualized
    b. Spoken or written
    c. What do you communicate?
        i. Goals for development

        ii. Production goals
    d. How often do you communicate?
28. Does the communication between production and the other functions work well?
    a. If yes, what is communicated?
    b. If no, what is the problem?
29. If a failure arises earlier or later in the product's value chain, how to you get information about the failure?
30. Do you have documentation/information about every process?
    a. How often are they updated?
    b. Is data estimated?
        i. Accuracy
    c. Who reviews the documentation?
    d. Are the instructions used?
31. If information is missing, how do you make decisions?
32. How is information saved?
    a. Does everyone know how to find it?

Final

33. What do you think you are working best with when it comes to quality?
34. Do you want to add something?
35. Can we come back to you with more questions?

Appendix II – Cost parameters from the literature

Prevention costs

(Harrington, 1987; Feigenbaum, 1991; Gryna, 1999; Giakatis et al., 2001)

Quality audits	Quality engineering
Process control	Field trials
Design and development of quality information equipment	Market research
Product-design verification	Customer audits and inspections
Systems development and management	Planned maintenance
New-products review	Corrective maintenance
Supplier quality evaluation	Preventive maintenance time
Training	Preventive maintenance meeting time
Education	Equipment capability analysis
Vendor assessment rating, and development	Design specification reviews
Certification and accreditation	

Appraisal costs

(Harrington, 1987; Feigenbaum, 1991; Gryna, 1999; Giakatis et al., 2001)

Testing	Organizing returns and replacements	Time-card review
Checking labor	Inspections at supplier's site	Purchase-order review
Setup for test or inspection	Checking procedures	Checking labor claims
Walk-through analysis	Liaise with customer	Order-entry review
Test and inspection equipment and material and minor quality equipment	Waiting to be sure of quality	Computer time

Quality audits	Material trouble	Information systems cost associated with supplier rating
Outside endorsements	Test equipment records	Safety review (operator safety)
Maintenance and calibration of quality information test and inspection equipment	Quality department administration	Instruction procedures/document review
Field testing	Training of quality assurance personnel	More than one manager's signature on a document
Incoming inspection and test	Training of inspection and test personnel in any area	Upper management meetings with employees
In-process inspection and test	Invoicing review	Management meetings with customers
Final inspection and test	Calibration/maintenance of production equipment used to evaluate quality	Security checks
Document review	Field performance testing	Safety checks
Drawing checking	Sorting	Product design review
Evaluation of stocks	Employee inspection of completed work	Maintaining accuracy of test equipment

Internal Failure costs

(Harrington, 1987; Feigenbaum, 1991; Gryna, 1999; Giakatis et al., 2001)

Scrap	Machining defective materials	Troubleshooting cost
Rework	Lost production	Corrective action
Material-procurement costs	Isolation of causes of failure	Analysis of scrap
Loss of missing information	Discount on goods accepted on concession	Analysis of rework
Failure analysis	No planned job	Engineering travel and time spent on problems
One hundred percent sorting inspection	Equipment failure loss	Modifications to process
Reinspection	Interruption due to replacement of parts	Temporary (soft) tooling
Retest	Delay due to ill design and plan	Cost-reduction activities

Changing processes	Adjustment	Billing-error cost
Redesign of hardware	Start-up	Inventory out of control
Redesign of software	Minor stoppages	Expediting cost
Downgrading	Speed down loss	Supplier-cancellation cost
Variable of product characteristics	Additional rework	Improper payments to suppliers
Unplanned downtime of equipment	Idle loss cost of machine out of production chain	Financial report corrective action cost
Inventory shrinkage	Internal failure	Retraining
Variation of process characteristics from "best practice"	Installation failure cost	Rewriting/updating instructions/documents/invoices
Missed schedule	Handling employee complaints	Trying to meet bad estimates
Time spent by higher-level people doing low-level jobs	Incorrect labor level	Drafting errors
Overdue cost	Time spent investigating non-existent problems	Replacing tool and tester because engineering changes made them obsolete
Waiting costs	Time lost because reports are wrong	Accidents, injuries
Theft	Profit lost because reports are not on time	Labor-utilization index less than 1
Lateness (failure to respond)	Unused reports	Unused floor space
Incorrect time estimates/records	Misfiled information	Change order due to errors
Equipment-utilization index less than 1	Doing things that don't need to be done	Processing a suggestion more than once
Not following procedures	Material delays	Damaged goods and equipment
Personnel injuries	Lost time because work area is not laid out correctly	Not planned relocations/moves/rearrangements
Overtime due to problems	Non-value adding activities	

External Failure costs

(Harrington, 1987; Feigenbaum, 1991; Gryna, 1999; Giakatis et al., 2001)

Product service	Allowances	Analysis and correlation of feedback data
Product liability	Penalties due to poor quality	Field repairs
Product recall	Rework on support operations	Canceling suppliers
Customer returns	Revenue losses in support operations	Verifying failure
Analysis of returns	New customers lost because of quality	Salary for repair personnel
Warranty charges	New customers lost because of lack of capability to meet customer needs.	Downtime charges
Analysis of warranty	Free-of-charge replacements	Modification delays and costs
Complaint adjustment	Receipt and disposal of defective goods	Shortages of components or materials
Overdue costs	Costs due to waiting	Loss of customer Goodwill
Bad debts	Sales and service reports	Accidents/injuries
Theft	Failure reports	Loss of sales because of poor service
Product or customer service because of errors	Direct customer contact on field problems	Engineering-change analysis
Engineering time and travel on problems in field	Customer change requirements	Documentation changes
Field inventory	Accounting cost related to returned items	

Appendix III – Cost parameters from expert study

R&D	Production	After Sale	Common
More generations of prototypes than expected	Scrap during production	Warranty	Customers describe the problem faulty
Products sold to not suitable customers	Scrap due to damages in production	Claims	Problems in software
Scrapped pre-serials	Unplanned set-up time	Repair	Problems in hardware
Rework	Stop in production	Rework	Problem-solving time
Redesign	Equipment disturbance	Commercial goodwill	Lead-time in quality issues
Retest	Production downtime	Technical goodwill	Motivation and Engagement
Unspecified development process	Equipment collapse	Campaigns	Laziness
Risk-taking by taking shortcuts	Unplanned equipment wear		Person injury
	Surplus stock		Safety equipment
	Lack of material and stock		Absence due to illness
	Delivery disturbance		Over-time
	Inspection of incoming material		Effective work time
	Rework		Lack of time
	Repair of product		No money for quality
	Equipment utility		Lack of resources
	Unplanned equipment maintenance		Education
	Assembly failures		Not knowing what to measure
	Deviation from first time through		Lack of communication

	Low inventory turnover		Lack of information
	Inspection during production		Lack of documentation
			Lack of feedback
			Not reported work
			Hiding of information
			Not updated process
			Not updated instruction
			Waiting time
			Prioritizing new projects before quality

Appendix IV – Cost parameters of the tool

Research and Development

Rework	
Redesign hardware	Unplanned or unnecessary redesign of hardware. Usually occurs in later product development process. e.g. drawing errors in design phase, due to lack of planning.
Redesign software	Unplanned or unnecessary redesign of software. Usually occurs in later product development process.
Retest due to redesign	New test due to redesign of hardware or software.
Reinspection due to rework	New inspection due to rework. e.g. prototype inspection, drawing checking and product design review.
Higher number of prototypes than planned	E.g. Product characteristics or material requirements cannot be met.
Higher number of pre-serials than planned	E.g. Product characteristics or material requirements cannot be met.
Additional cost	*Add cost parameter if needed.*
Delay	
Internal Delays	E.g. Missed deadlines.
Additional cost	*Add cost parameter if needed.*
Personal	
Administration	Administration work and tools e.g. Change of password, IT-handling and unnecessary software licenses.
Overtime	Unplanned overtime.
Additional cost	*Add cost parameter if needed.*

Production

Scrap	
Incoming material/component	Scrap due to errors/failures of incoming material/component.
In production process	Scrap due to errors/failures due to production process.
Final product	Scrap due to errors/failures of final products.
Additional cost	*Add cost parameter if needed.*
Rework	
Rework of production activity	Includes rework of new product and adjustments of product in production process.
Repair of final product	Adjustments of final product to make it complete.
Retest due to rework	New test due to rework of production process.
Reinspection due to rework	New inspection due to rework of production process.
Additional cost	*Add cost parameter if needed.*
Production equipment	
Equipment downtime	Include both shorter and longer equipment downtime. Do not include set-up time.
Equipment collapse	The equipment needs to be replaced = new equipment cost. The time the equipment is down will be seen as an "Equipment downtime cost".
Equipment utility	Equipment efficiency is calculated as OEE, will get the unit %.
Unplanned set-up time	Do not include this parameter if the unplanned set-up time is included in another cost parameter.
Unused workspace	Workspace that not are used for value-adding activities.

Additional cost	*Add cost parameter if needed.*
Inspection	
Incoming material inspection	Inspection of incoming material.
Order-entry review	Review of order to make sure you got the right things.
In-process inspection	Inspection in process.
Final inspection	Inspection of final product.
Review of inspection data	Take advantage of the collected data.
Additional cost	*Add cost parameter if needed.*
Stock	
Stock	Surplus stock, Turnover rate or Utilization of area.
Missing part and material in stock	Parts and materials are missing when needed.
Internal delays in production	E.g. Time spent in waiting for products/information to be able to start working.
Additional cost	*Add cost parameter if needed.*
Personnel	
Administration	Administration work and tools. E.g. Change of password, IT-handling and software licenses.
Back-up in case of illness	Only consider when back-up is required.

Overtime	Unplanned overtime.
Additional cost	*Add cost parameter if needed.*

After Sale

Product/Service failures	
External Claim	External claims may include other cost parameters. Distribute as much as possible. Otherwise present it here. Tips for identification: Check variance report.
Recall	A company needs to recall products from customer. e.g. Freight charge.
Return	Products back from the customer.
Overdue cost charged from customer	Charge from customer due to delivery delay.
Sorting inspection	Sorting and inspection costs to investigate if products are correct. Can be both in-house and at customer field.
Additional cost	*Add cost parameter if needed.*
Customer satisfaction	
Warranty cost	Cost due to warranty.
Campaign	Cost due to campaign.
Goodwill technical	Cost due to technical goodwill.
Goodwill commercial	Cost due to commercial goodwill.
Free of charge replacement	Product replacement because of e.g. customer claims or recalls.
Discount	Downgraded goods sold cheaply.
Additional cost	*Add cost parameter if needed.*
Service/Repair	
Repair of returned product	Cost du to repair of returned product.

Unplanned product service	Cost due to unplanned product service.
Additional cost	*Add cost parameter if needed.*
Personnel	
Administration	Administration work and tools. E.g. Change of password, IT-handling and software licenses.
Overtime	Unplanned overtime.
Additional cost	*Add cost parameter if needed.*

Common CoPQ

Common CoPQ	
Lead-time in quality issues	The time period from reported claim until the problem is solved.
Problem-solving resources	How much time has been dedicated a problem.
Failure analysis, search for failure, report	How much time it takes to search for failures.
Expediting costs	E.g. express freight due to delayed products.
Person injury	Sickness compensation due to injuries from work.
Additional cost	Add cost parameter if needed.

Appendix V – Selection of the tool

Company	Company X	**Consultant**	Consultant A & Consultant B	**Date**	16-04-28
Limitation of investigation	Investigation limitation: consider R&D, Production and After Sale			**Time period of data collection**	4 month

Cluster	Cost parameters	Cost type	Tips how to measure/identify	Cost	Unit	Total cost per parameter	Est. 1	Est. 2	Est. 3	Comment
Scrap	Incoming material/component	Material cost	(SEK*weight), (SEK*m2), (SEK*number of components)	3000,00	SEK	3000,00		x		
	In production process	Material cost	(SEK*weight), (SEK*m2), (SEK*number of components)	300,00	SEK	7800,00	x			
		Labor cost	(Labor cost*hours for operation)	4000,00	SEK		x			
		Production cost	(operating cost*h)	3500,00	SEK			x		
	Final product	Material cost	(SEK*weight), (SEK*m2), (SEK*number of product)	500,00	SEK	9000,00	x			
		Labor cost	(Labor cost*hours for operation)	4000,00	SEK				x	
		Production cost	(operating cost*h)	4500,00	SEK			x		
	Additional cost			-						
Total Scrap				**19800,00**	**SEK**	**19800,00**	**3**	**3**	**1**	
Rework	Rework of production activity	Material cost	(SEK*weight), (SEK*m2), (SEK*number of components), (SEK*number of product)	500,00	SEK	3500,00		x		
		Labor cost	(Labor cost*hours for operation)	2000,00	SEK			x		
		Production cost	(operating cost*h)	1000,00	SEK			x		
	Reparation of final product	Material cost	(SEK*weight), (SEK*m2), (SEK*number of components)	-		0,00				
		Labor cost	(Labor cost*hours for operation)	-			x			
		Repair equipment cost	Operating cost	-						
	Retest due to rework	Labor cost	(Labor cost*hours for operation)	1000,00		1200,00		x		
		Test equipment cost	Operating cost	200,00					x	
	Reinspection due to rework	Labor cost	(Labor cost*hours for operation)	2000,00		2000,00		x		
	Additional cost			-						
Total Rework				**6700,00**	**SEK**	**6700,00**	**1**	**5**	**1**	
Production equipment	Equipment downtime	Lost production cost	(operating cost*h)	6000,00	SEK	10500,00	x			
		Labor cost	(Labor cost*downtime)	4500,00	SEK			x		
	Equipment collapse	New equipment cost	SEK	1500,00	SEK	1500,00		x		
	Equipment utility	OEE (Overall Equipment Efficiency)	(Good Count*Ideal cycle time/Planned production time)	87%	%			x		
	Unplanned set-up time	Labor cost	(Labor cost*hours for set-up operation)	-		0,00		x		
		Production cost	(operating cost*hours for set-up)	-				x		
	Unused workspace		facility cost(SEK/m2)*unused workspace(m2)	-		0,00		x		
	Additional cost									
Total Production equipment				**12000,00**	**SEK**	**12000,00**	**1**	**6**	**0**	
Inspection	Incoming material inspection	Labor cost	(Labor cost*inspection time)	1000,00	SEK	1000,00		x		
	Order-entry review	Labor cost	(Labor cost*inspection time)	1000,00	SEK	1000,00		x		
	In-process inspection	Labor cost	(Labor cost*inspection time)	1500,00	SEK	1500,00	x			
	Final inspection	Labor cost	(Labor cost*inspection time)	1000,00	SEK	1000,00	x			
	Review of inspection data	Labor cost	(Labor cost*h)	-		0,00	x			
	Additional cost									
Total Inspection				**4500,00**	**SEK**	**4500,00**	**3**	**2**	**0**	
Stock	Stock	Surplus stock	(SEK)	100000,00	SEK	100000,00	x			
		Turnover rate	Sold products/stock	-						
		Utilization	m2 stock/m2 production plant	-						
	Missing part and material in stock	Time		-						
	Internal delays in production	Time		25,00	h			x		Present as time
	Additional cost									
Total Stock				**100000,00**	**SEK**	**100000,00**	**1**	**1**	**0**	
Personnel	Administration	Labor cost	(Labor cost*hour for operation)	3500,00	SEK	4000,00	x			
		Software license	SEK	500,00	SEK		x			
	Backup in case of illness	Labor cost	(Labor cost*hour for operation)	300,00	SEK		x			
	Overtime	Labor cost	(Labor cost*hours for operation)	-					x	
	Additional cost									
Total Personnel				**4300,00**	**SEK**	**4000,00**	**3**	**0**	**1**	
Others	Internal Claim		SEK, number of claims	5,00	No					
	Additional cost									
Total Others				**0,00**	**SEK**		**0**	**0**	**0**	
TOTAL Production				**147300,00**	**SEK**	**147000,00**	**12**	**17**	**3**	

Appendix VI – Survey for investigating soft CoPQ

Your answers of this survey is a contribution towards identify and quantify Cost of Poor Quality of Company X. Cost of Poor Quality are the costs which would be eliminated if a company's products and processes in its business were perfect. The reason to why these costs should be identified and quantified is to highlight what in the company that could be improved.

We find your answers very valuable since the survey mainly consider soft factors that are challenging to identify through alternative ways. Your answers will be anonymous and will only be presented together with other respondents' answers.

We who are conducting the investigation are employed at a consultancy firm, located in Gothenburg. The consultancy firm works for reducing our customers' Cost of Poor Quality and generate profit.

Below you will find 17 questions, divided into four categories. You respond the questions by marking the box you find most consistent with your opinion.

For any questions, please contact X on phone: _________ or mail: __________

Information	Always	Often	Some-times	Seldom	Never
Do you consider that you have the information you need to perform your work?	○	○	○	○	○
Do you consider that you have the documentation you need to perform your work?	○	○	○	○	○
Do you consider that the communication between your department and other departments work well?	○	○	○	○	○
Do you consider that you get the feedback you need to perform your work?	○	○	○	○	○
Do you consider the instructions and/or documentation related to your work is up to date?	○	○	○	○	○
Do you follow instructions given?	○	○	○	○	○

Resources	100%	75%	50%	25%	0%
How much of your working week do you spend on value-added work?	○	○	○	○	○
How far do you think you have the time needed to perform your work?	○	○	○	○	○
How much of your working time do you feel that your work is properly manned?	○	○	○	○	○
How far do you think you have the right competences to perform your work?	○	○	○	○	○
How far do you think that the right competences are at the right place in the company?	○	○	○	○	○

Problem solving	Always	Often	Some-times	Seldom	Never
Do you consider that you take decisions based on facts?	○	○	○	○	○
Do you consider that new projects take priority over quality projects of older products?	○	○	○	○	○
Do you consider yourself solving problems that turn out not exist?	○	○	○	○	○

Person	Always	Often	Some-times	Seldom	Never
Do you feel motivated in your work?	○	○	○	○	○
Do you consider that you achieve predetermined goals in your work?	○	○	○	○	○
Do you report your work?	○	○	○	○	○