LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
Faculty of Technology
Department of Industrial Management

MEASURING COST OF POOR QUALITY IN INDUSTRIAL ELECTRONICS

Supervisor: Prof. Janne Huiskonen
Instructor: Lis. Tech. Harri Heimonen

Lahti, January 15, 2012

Juhana Junes
Mariankatu 6 A 3
15110 Lahti
040 7458062

ABSTRACT

Student: Väinö Juhana Junes **Title:** Measuring cost of poor quality in Industrial Electronics.
Department: Department of Industrial Management
Year: 2012 **Location:** Lahti
Master’s thesis. Lappeenranta University of Technology. 143 pages, 52 figures, 5 tables and 3 appendixes. Supervisor: Professor Janne Huiskonen Instructor: Lis. Tech. Harri Heimonen
Keywords: cost of quality, quality improvement, and supplier performance ratings.
Quality is not only free but it can be a profit maker. Every dollar that is not spent on doing things wrong becomes a dollar right on the bottom line. The main objective of this thesis is to give an answer on how cost of poor quality can be measured theoretically correctly. Different calculation methods for cost of poor quality are presented and discussed in order to give comprehensive picture about measurement process. The second objective is to utilize the knowledge from the literature review and to apply it when creating a method for measuring cost of poor quality in supplier performance rating. Literature review indicates that P-A-F model together with ABC methodology provides a mean for quality cost calculations. These models give an answer what should be measured and how this measurement should be carried out. However, when product or service quality costs are incurred when quality character derivates from target value, then QLF seems to be most appropriate methodology for quality cost calculation. These methodologies were applied when creating a quality cost calculation method for supplier performance ratings.

TIIVISTELMÄ

Tekijä: Väinö Juhana Junes

Työn nimi: Huonon laadun kustannusten mittaaminen elektroniikkateollisuudessa.

Osasto: Tuotantotalous

Vuosi: 2012 **Paikka:** Lahti

Diplomityö. Lappeenrannan teknillinen yliopisto.

143 sivua, 52 kuvaa, 5 taulukkoa ja 3 liitettä.

Tarkastaja: Professori Janne Huiskonen

Ohjaaja: Tekniikan lisensiaatti Harri Heimonen

Hakusanat: huonon laadun kustannukset, laadun parantaminen, ja toimittajan suorituskyvyn arviointi.

Laatu ei ole ilmaista vaan sen avulla voidaan saavuttaa suurempi liikevoitto. Jokainen dollari, jota ei ole käytetä huonon laadun kustannuksiin, voidaan siirtää voitoksi yrityksen tulosriville.

Tämän tutkimuksen päätavoitteena on tarkastella kuinka huonon laadun kustannuksia tulisi mitata teoreettisesti oikein. Työn alussa lukija johdatetaan laatukustannusten ajattelutapaan. Useita huonon laadun kustannusten laskentatapoja esitetään kokonaiskuvan luomiseksi. Työn toisena tavoitteena on hyödyntää kirjallisuuskatsauksen oppeja kehittäessä toimittajien suorituskyvyn arviointiin soveltuvaa huonon laadun kustannusten laskentamallia.

Kirjallisuuskatsauksen mukaan P-A-F malli yhdessä ABC metodiikan kanssa ovat tarkoituksenmukaisia huonon laadun kustannusten laskemiseen. Mallit antavat vastauksen siitä, mitä tulee mitata ja miten mittaus tulee suorittaa. QLF malli sopii parhaiten tilanteisiin, joissa laatukustannukset syntyvät laatuarvon poiketessa tavoitearvosta. Näitä malleja hyödynnettiin toimittajan suorituskyvyn arvioinnin huonon laadun kustannusmallin luomisessa.

ACKNOWLEDGEMENTS

First of all I would like to thank my coworkers at case company for providing lot of valuable information and support during the process. Without your valuable help this would not have been possible.

Specially, I want to thank my instructor, Lis. Tech. Harri Heimonen, and other members of steering group, Mr. Markku Huotari and Ms. Nelli Nivalainen, for all the advice, encouragement and trust they had on me during this research. In addition I am also grateful to my supervisor, Professor Janne Huiskonen, for the guidance.

Finally, I would like to thank my family and friends for all the support during my studies in Lappeenranta University of Technology.

Lahti 15.01.2012

Juhana Junes

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ABBREVIATIONS

ABC	Activity-Based Costing
ASQ	American Society for Quality
ATE	Automatic Test Equipment
COPQ	Cost of Poor Quality / Cost Opportunities by Perfecting Quality
EM	Emerging Markets
ERP	Enterprise Resource Planning
DMAIC	Define, Measure, Analyze, Improve, Control
FLOP10	A quality project to improve supplier performance
GATE-model	Process Development method
GATE	Decision point within a project
LTB	Larger-the-Better Quality Loss Function
MM	Mature Markets
NTB	Nominal-the-Best Quality Loss Function
OEM	Original Equipment Manufacturer
OTD	On-Time-Delivery
OPEX	Operational Excellence
OQD	On-Quality-Delivery
PAF	Prevention – Appraisal – Failure
POL	Purchase Order Line
PONC	Price of nonconformance
ProDeM	Process Development Model
PPM	Parts Per Million
QCPI	Quality Cost Performance Index
QLF	Quality Loss Function
SCM	Supply Chain Management
STB	Smaller-the-Better
TQC	Total Quality Control

1 INTRODUCTION

1.1 Background and motivation

According to Philip Crosby quality is free and unquality things that are all the actions that involve not doing jobs right the first time cost money. Quality is not only free but it can be a profit maker. Every dollar that is not spent on doing things wrong becomes a dollar right on the bottom line. Therefore increased quality can increase company's profits by an amount equal to 5 to 10 percent of its sales. That's a lot of money for free (Crosby.1979. p.2). Camal & Elshennawy.2004, p.291 highlights that according to quality experts a typical company can save more money by halving their costs of poor quality than doubling their sales. According to Superville and Gupta, p.419 quality is not only a profit maker in terms of saving but is also an important strategic dimension and a key competitive weapon that should not be ignored by any organization.

If the cost of poor quality is not measured, it cannot be controlled. There is a demand to exchange the cost of poor quality to figures that can be monitored with financial measurements at the higher levels of company's hierarchy. This particular ideology gets accentuated in the current economic climate as case company needs to accelerate its efforts in reducing waste throughout its operating cost base.

It is determined within case company that poor supplier On-Time-Delivery (OTD) and On-Quality-Delivery (OQD) performance are major contributors to COPQ and worst performing supplier performance suppliers have a significant impact on operational efficiency. Hence, case company is at the moment involved in various projects, such as FLOP10, that deals the issue of cost of poor supplier quality. This project supports and broadens company's examination of costs of poor quality.

The FLOP10-project was launched in 2007 in order to improve supplier on-time and on-quality-delivery performance of top 10 mature markets (MM) and emerging markets (EM) suppliers. The objective of FLOP10-project is therefore to track and improve the performance of top 10 MM and EM suppliers by value and to implement related improvement projects in order to bring supply chain performance up to the required level so that suppliers can effectively support case company assembly and manufacturing operations and to reduce associated cost of poor quality.

Case company's objective is to broaden quality cost calculations across its whole supplier base as currently FLOP10 focuses only lowering quality costs of ten worst suppliers. In addition there is a need to improve current quality cost calculation method.

1.2 Objectives and research problem

Case company is going to lay out a global framework for supplier performance rating at group level in 2012. Results of this study will be taken into consideration when the building of a cost of poor quality measurement tool for supplier performance ratings takes place. In addition there is an interest improving current quality cost measurement method that is applied in FLOP10 project.

Although case company is involved with various quality cost measurement they do not have unanimous and comprehensive understanding about how the costs of poor quality of on-quality-delivery and on-time-delivery are calculated correctly. Therefore the main objective of this thesis is to give an answer on how cost of poor quality can be measured theoretically correctly. Different calculation methods for cost of poor quality are presented and discussed in order to give comprehensive picture about measurement process.

In addition there is a need to broaden current measurement from 10 worst suppliers to whole supplier base. Therefore the second objective is to utilize the knowledge from the literature review and to apply it when creating a method that can be applied measuring cost of poor quality in supplier performance rating. Hence, the purpose is to create measurement method to measure cost of poor quality with required formulas as an end-product that can be used in supplier performance ratings. The observation will be carried within selected business unit in the case company but the findings will be also given to other business units globally as part of FLOP10-project.

However, measurements itself does not have any impact on company's operating cost base only the actions improving opportunities found using cost of poor quality measurement tools can lead to improvements. In addition for only giving theoretical study of measuring cost of poor quality the paper contains methodology for finding most appropriate opportunity for improvement among many alternatives and justification method for improvement. At operating level this means that results of measurement will be discussed together with suppliers and root causes for poor performance will be discovered. In addition, corrective actions will be carried out across supply chain in order to improve quality level. These corrective actions may include alterations in components used or in worst scenario supplier is replaced because of poor performance.

1.3 Research method and Structure of the thesis

The purpose for this paper is to academically determine how to measure the cost of poor quality so that findings can be used when modifying supplier performance rating-tool to include COPQ-calculations in all required areas. Therefore this particular study is a combination of academic research and a case study. This particular research method divides this study into preceding two parts. In academic research-part the purpose is to present existing COPQ-frameworks that could be applied when determining related measuring methods and simulations of "cost of poor quality" for selected subcategories of supplier performance rating tool. According to Miguel & Pontel.2004, p.312-313 combination of literature research that is concurrent with action can be referred as an action research.

The problem solving in the case study was an application of the scientific method of fact finding and experimentation to practical problem that required active co-operation not only with the steering group but also with other employees of different functions. The case study was carried out as a cyclical process of planning, taking action, and evaluating the action. It contains actions of gathering data, feeding data to steering group, analyzing the data, planning and taking action and evaluating results.

Process improvement project such as ramp-up and ramp-down projects are carried out with ProDeM - Gate Model for Process Development in Drives. GATE-model support process development projects in the areas of quality and operational excellence. Therefore it is appropriate to use this model also in this study of cost of poor quality. (Harri Heimonen, 2011)

The GATE-model divides the participants of the project into implementation group and into steering group. The objective of the implementation group is to take determined actions in order to implement the changes needed to go through the next gate. Steering group is to support and to guide the execution group to end up with the best possible result. (Harri Heimonen, 2011)

GATE-model separates a project to the sequential decision points that are called as gates. All the gates that are used in GATE-model are determined more carefully in appendix 1. When project reaches a decision point, the whole project is evaluated from a business and strategic point of view and the project is reassessed to determine whether to continue a project. This procedure ensures that project is still viable and the management and project manager are aligned to the objectives for the next phase and overall project goals. Decision to continue may include changes in scope and time plan. Any decision to proceed will include appropriate financial approval from management. The following figure 1 illustrates how GATE-model functions in decision point. (Harri Heimonen, 2011)

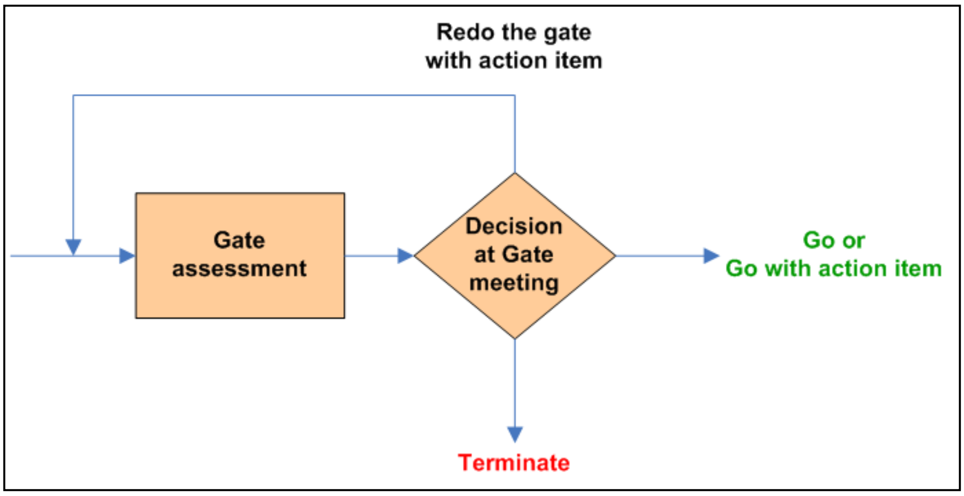


Figure 1. Decision point in GATE-motel (Harri Heimonen, 2011)

The structure of the thesis is based on four sequential phases that are introduction, literature research, a case study and summary. A detailed content of each stage can be seen in following figure 2.

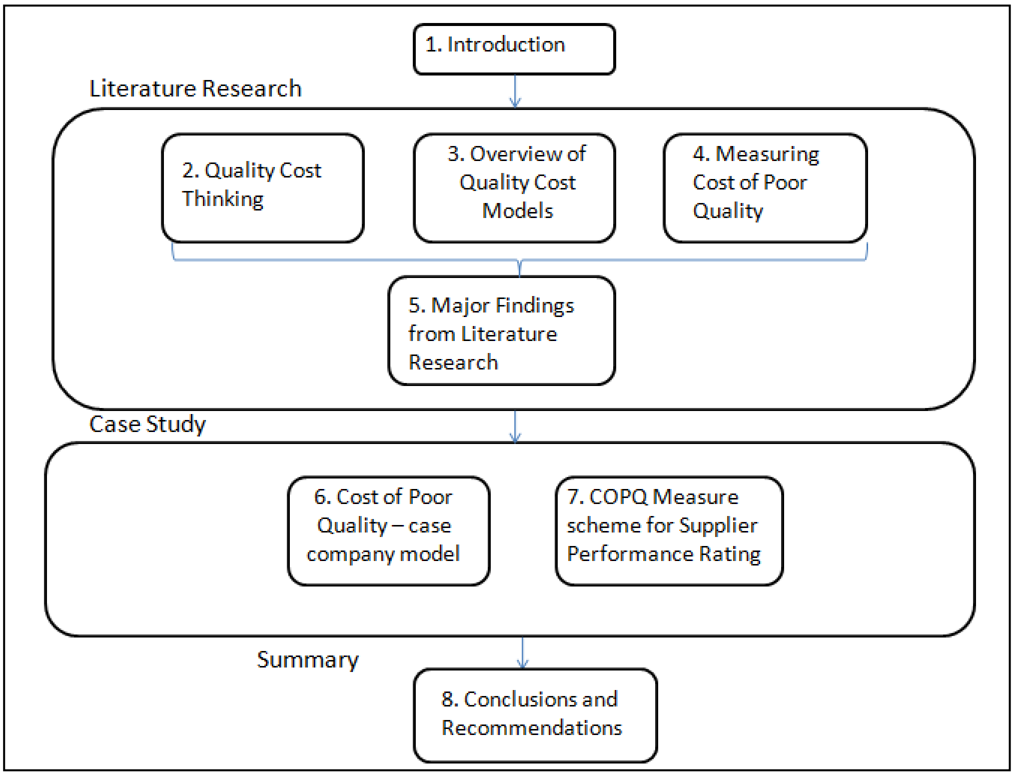


Figure 2. Structure of thesis

1.4 Limitations

Quality costs systems serve organizations with many different functions. However, in this master’s thesis only its measurement tool characteristics are examined. It was decided that anything will not be excluded from literature review in the beginning of the investigation process. Discoveries of investigations are presented to steering group in group meetings in which discussion about relevance of topics is hold. This particular course of action seems to be appropriate in this master’s thesis as the purpose is determine how cost of poor quality is determined theoretically correctly and to apply the knowledge acquired from literature research in case study

Although COPQ-calculations should include all related elements from both direct and indirect COPQ, this particular study only encompasses direct costs of cost of poor quality. This specific defining has been agreed because elements and costs related to direct COPQ can be uncovered relatively accurately using logical approaches, however, the elements and costs related to indirect COPQ are obscure and therefore estimations would be just estimations without any theoretical or logical basis. This particular study, however, highlights that any COPQ-calculations are just indicative as it really hard or even impossible to capture all the related costs in calculations. Despite of the limitations of COPQ-calculations this particular study focuses on capturing the main cost factors as what is measured can be improved. According to Camal & Elshennawy.2004, p.291 the loss of revenue due to any misconception of customer expectations in determined targets involving quality, delivery, schedules and as well as dimensions can be substantial and therefore should not be combined with other cost elements. Having this in mind this paper only describes the cost elements of indirect poor quality costs as it is seen to give essential giving the wider overall picture of cost of poor quality. However, these elements will be excluded from actual case in which the poor quality of supplier performance rating is evaluated.

Co-operation and development are excluded when evaluating costs of poor quality for categories of supplier performance rating. This item contains three subcategories that are technical co-operation, commercial co-operation and development. The reason for excluding these items is that in supplier performance rating the measurement of these items is not based on performance measurement but on objective evaluation based on sourcing, purchasing and technical personnel of case company.

Particular model for calculating that is presented as the outcome of this study does not take quality learning into account. Therefore the concept of quality learning curve that suggests that quality learning will lead to fewer product or operational defects is excluded from this study. This paper focuses only determining the term of cost of poor quality and how it can be measured and presents model for evaluating costs associated to the different subcategories of the supplier performance. However, as gathering quality cost information and analysis are essential components of evaluating quality costs and therefore those subjects are employed as part of investigation of how quality costs should be measured.

It needs to be noted that this is a public version of master’s thesis. Hence, all the figures in calculations presented in case study have been amended in order to avoid any copying from competitors.

2 QUALITY COST THINKING

The word “quality” comes from Latin word “qualitas” that is translated as a character. However, the determination for quality is not that simple as the translation is as there is vast number of definitions in which advocates are not unanimous (Fransson & Turesson.2009, p.12). This makes business of quality management challenging. Quality is often determined as “fitness for use”, or “grade of excellence”, or as “an essential character of something” (ASQC Quality Costs Committee.1989, p.125). According to Fransson & Turesson.2009, p.12 product quality consist eight dimensions that are described in following table 1:

Table 1. Dimensions of product quality. (Fransson & Turesson.2009, p.12)

Reliability	How often faults occur and how serious they are
Performance	Characteristics of importance for the customer
Serviceability	How easy it is to find, locate and eradicate faults
Environmental friendliness	The product’s impact on the environment
Appearance	Aesthetics parameter created by design and colour
Absence of defect	That the product does not have faults or shortages when it is bought
Security	That the product does not cause harm to person or property
Durability	That the product can be used, stored and transported without being fatigued or damaged

As seen from previous determinations, most of quality books use only a short paragraph to explain what quality is. The determination used by Juran et al.1998, p.2.2 divides quality into two different divisions. In the first determination the meaning of quality is seen as potential income. Therefore higher level of quality will provide higher level of customer satisfaction and therefore hoping to increase the income. However when improving quality also related costs increase accordingly and therefore higher quality costs more. In the second determination quality is seen as freedom from deficiencies. According to this determination quality products and services are free from errors and costs that are related to these errors. Therefore this determination claims that higher quality costs less.

According to Crosby quality need to be determined in the way that it is measurable or expandable and easy to communicate (Juran et al.1998, p.2.2). According to Crosby quality is defined as “conformance to requirements” which means that it can be managed (Crosby.1980, p.3-15; Crosby.1997, p.24-29). According to Juran’s and Gryna’s determination of quality it also has two aspects, quality of design and quality of conformance. Quality of design refers to the planned quality of a product or service. The designed quality of a product or service may include specifications i.e. for product reliability, operating costs (ASQC Quality Costs Committee.1989, p.125; ASQC Quality Costs Committee.1987b, p.1). Burgess.1996, p.8-9 also supports Juran’s and Gryna’s view of thinking. However he highlights that the main focus in many discussions of quality costs is on quality at the process level. Therefore quality determinations are clarified and measured as conformance quality.

According to Crosby’s determination of quality, the requirements are the details of the business that result in customers and employees receiving what they have been led to expect (Crosby.1980, p.3-15; Crosby.1997, p.24-29). Juran et al.1998, p.2.2-2.3 continues that it is assumed that product that conformed to specifications would also meet customer needs. This is a logical assumption as departments of company have rarely a direct contact with customer. Therefore this assumption may be actually faulty as customer needs may include many various subjects that are not found in specifications. The conclusion of Crosby’s and Juran’s determination is that quality departments need to revise their definition of quality to include customer needs that are not already included as a part of product or service specification (Juran et al.1998, p.2.2-2.3). Crosby highlights that management is responsible for creating clear requirements to be constantly improved. After all, a part of top management’s job is to make certain that all management’s functions have the opportunity to perform their responsibilities. The problem may lay that persons at top management level might have limited perspective about overall quality. (Crosby.1980, p.3-15; Crosby.1997, p.24-29)

The second misbelief about quality is that quality is intangible and therefore not measurable. According to Crosby anything can be measured if it is a must. He continues that quality needs to be measured by the cost of quality which is the expense of nonconformance – the cost of doing things wrong. Therefore quality should be measured by the oldest and most respected of measurements – cold hard cash as everything else is measured in that way (Crosby.1980, p.15-16; Crosby.1997, p.24-29.) This can be done by including the "price of non-conformance", PONC into performance calculations. PONC can be used in determining subject of quality improvements (Crosby.1997, p.24-29.) In this study PONC and "cost of poor quality, COPQ" are seen as synonyms and the latter term is used throughout this study as it is the term the case company is using in similar situations. According this determination there are two types of costs of quality: conformity costs that are necessary costs of quality and non-conformity costs that area avoidable costs of quality (figure 3). (Sissonen.2008, p.42)

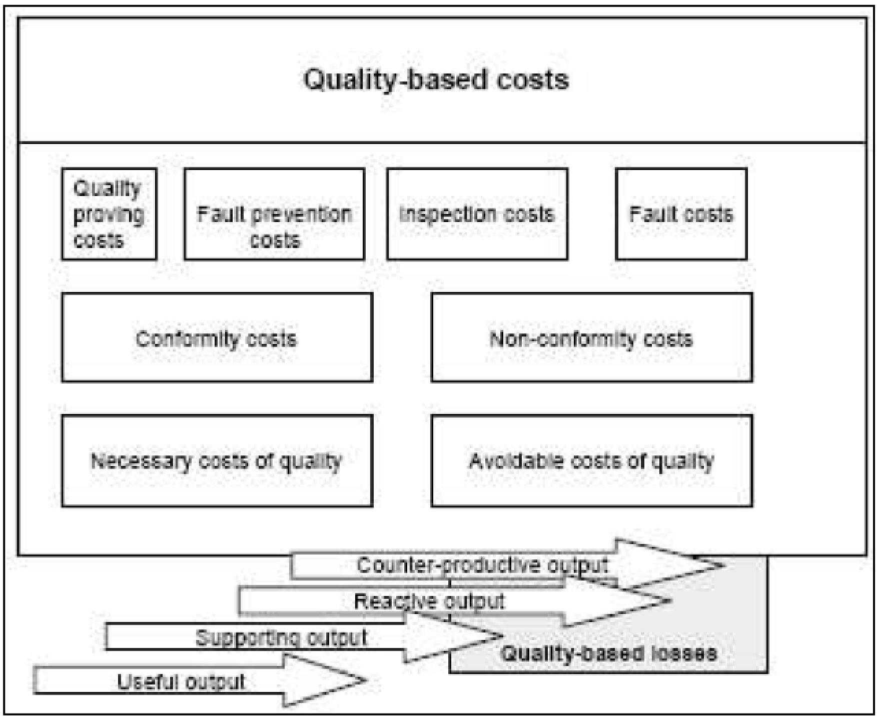


Figure 3. Necessary and avoidable costs of quality (Sissonen. 2008, p. 45)

The "1-10-100 Rule" describes well the accumulation of quality related costs, even though this "rule" has no specific research background. This widely used rule of thumb suggests that a quality problem costing only $1 to prevent in the first place would cost about $10 to correct if discovered during in-house processes and up to $100 if the quality problem is delivered to customer and it need to resolve in the field (Sissonen, 2008, p. 45). Therefore it is necessary to apply cost of poor quality to the impact that errors have on the customer. This concept also emphasis the importance of taking actions to quality problems at supplier's side, as costs of poor quality will increase as moving down the stream towards the end-customer. (Harrington.1987, p.6)

Many believe that there is an “Economics of Quality” meaning that the better the quality the greater costs to achieve it. According to this particular belief, improvements in quality create only costs. However, it is explained in this chapter that improvements in quality create savings and increased market share (Crosby.1997, p.24-29.) According to above information there are two theoretical models available which both tries to find the optimum between the costs and the quality. According to the classic model of optimum quality costs, illustrated in figure 4, achieving 100 % defect free products is not appropriate as appraisal and prevention costs are assumed to increase exponentially when approaching 100 % quality level. Therefore, the optimum level suggested by the classic model is found somewhere below the 100% quality level. (Sissonen. 2008, p. 42-43)

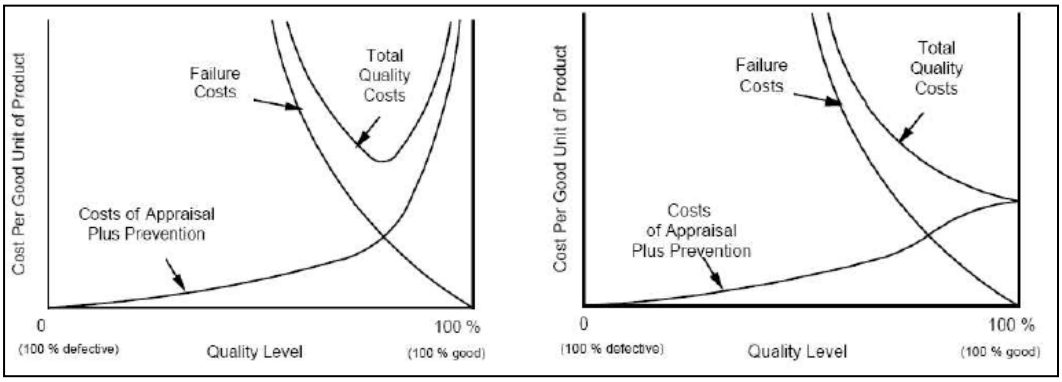


Figure 4. Traditional vs. new model of optimum quality costs (Sissonen, 2008, p. 43)

The new model of optimum quality costs has gained ground in a few last decades. The new model suggests that approaching 100 % quality level does not necessarily increase the total quality costs. This model has two arguments. Firstly, does it really take infinite investments (for appraisal and prevention) to reach zero defects and secondly the loss of sales could be significant under 100 % quality level. With these arguments the model suggests that total quality costs have its minimum at the 100 % quality level (Sissonen.2008, p.43). The study presented by ASQC Quality Costs Committee.1989, p.126 support this latter argument that total quality costs would be minimum at the 100 % quality level. Their study, however, admits that there might be trade-offs between costs and quality of design but no trade-offs between costs and quality of conformance can be found. Their study continues that once the design is agreed the quality costs are associated with both ensurance and of conformity and the lack of conformity. According to this determination quality costs are restricted from costs associated with quality of conformance and therefore the company incurs the costs if the output fails to conform.

The best way to sum up the main factors about quality cost thinking is to use four sector determination of quality. Firstly, quality is conformance to requirements. Quality specifications are based on requirements and these requirements start with customers' needs. Secondly, quality-systems have got to assign the means for preventing defects. Therefore the ones who inspect outputs must know how to control the process. Thirdly, acceptable quality levels need to be defined as performance standards and these standards must require "zero defects". Fourthly, quality needs to be measured by calculating the price of poor quality. (Quality, Productive and Innovation.1987, p.268-293)

2.1 What is Cost of Poor Quality?

Terms "cost of quality" and "cost of poor quality" have been used as synonyms in various quality studies of cost of poor quality. However, the term "quality cost" gives a negative impression that reflects the thinking of the 1950s, when it was commonly believed that better-quality products cost more to produce (Harrington. 1999, p.223.) Also National Conference for Quality (1982) argued that quality is profitable, not costly. Therefore phrase “cost of quality” should not be used (Campanella.1999, p.3.) Because of these previously mentioned reasons the term “poor-quality cost” seems to be more appropriate than “cost of quality”. However, these both terms have similar content, which is to be a management tool that helps to indentify improvement opportunities, optimize the effectiveness of the improvement efforts, and to measure the progress that is being made to continuously improve. In other words cost of poor quality helps to reduce the cost associated with poor quality. (Harrington. 1999, p.223; Harrington.1987, p.XV)

Researchers were not unanimous about the determination of quality but they also disagree about what is “cost of quality”. At the moment there are two examples of definitions of “cost of quality” that are the costs of attaining quality and the costs of running a quality department (Fransson & Turesson.2009, p.18-19). According to Juran & Gryna.1988, p.4 cost of quality includes all the costs that would be saved in case there would not be quality problems. Cost of poor quality are the measures of the costs associated with the achievement or non-achievement of product or service quality (Sissonen. 2008, p.40). Campanella.1999, p.3 determines cost of poor quality to include all the costs that would not have been expanded if qualities were perfect. Therefore any company function can be responsible for redoing the work already accomplished. Philip Crosby 1980, p.11 determines cost of poor quality as the all expenses that occur when things are done wrong. Cost of poor quality includes the scrap, rework, service after service, warranty, inspection, tests and similar activities that are made necessary by nonconformance problems (Crosby.1980, p.11). “According to American Society of Quality (ASQ) definition, quality costs represent the difference between the actual cost of a product or service and what the reduced cost would be if there were no possibility of substandard service, failure of products, or defects in their manufacture” (Sissonen. 2008, p.40). According to Campanella.1999, p.4 the general description to costs of poor quality are the total costs of the cost incurred by:

- Investing in the prevention of non-conformances to requirements.
- Appraising a product or service for conformance requirements.

- Failing to meet requirements.

In other terms cost of poor quality represents "the difference between the actual cost of product or service and what the reduced cost would be if there was no possibility of substandard service, failure of products, or defects in their manufacture". (Campanella.1999, p.4)

According to Feigenbaum.1991, p.114 the quality cost system for total quality control involves three stages:

1) The identification of quality-cost items.
2) Quality-cost reporting that includes the related analysis and control.
3) The ongoing maintenance of the program to ensure that business objectives of higher quality at lower costs are met.

Quality management is a direct result of the realization that quality is the major factor in maintaining and increasing the customer base. Quality management program includes establishing performance standards in all operating areas, monitoring of performance, corrective action when deviation is found, and continuous improvement. Cost of poor quality-system provides guidance to quality management as it defines costs that are directly affected. (Campanella.1999, p.4)

Satisfactory quality goes hand-in-hand with satisfactory product and service cost. In the other hand unsatisfactory quality means unsatisfactory resource utilization including wastes of material, wastes of labor, and wastes of equipment use. All of these cause higher costs (Feigenbaum.1991, p. 109). The amount spent for the purpose of doing things wrong is a great deal of money. Many companies have difficulty (difficulties on) coming to grips with this measurement (Crosby.1997, p.49-50). In contrast, satisfactory quality involves satisfactory resource utilization and therefore consequently lowers costs (Feigenbaum.1991, p.109). According to Harrington 1987, p.3 poor quality costs your company money and good quality saves your company money. COPQ-system is only one of the many tools needed in a comprehensive quality system. However COPQ-system is important specifically because it directs management attention and measures the success of the company’s efforts to improve (Harrington. p. 3-4.) According to ASQC Quality Costs Committee.1989, p.19 the strategy of COPQ-systems is based on following three assumptions. Firstly, there is a root cause for each failure. Secondly, these root causes must be preventable. And thirdly, prevention is always cheaper.

2.2 Where is COPQ used?

Originally “cost of quality” was mainly related to the production and costs were relatively simply to implement because most of the data could be maintained in the accounting system. Therefore it was primarily used to measure manufacturing and warranty costs. This method was appropriate during 1960s and 1970s. However, according to the recent studies errors can occur in every department of company and therefore these studies emphasizes the need to also measure cost of poor quality in white-collar departments. This increased greatly the complexity of the data reporting system as there were need to collect information that was not collected before. The concept of non-value-added cost into calculations of cost of poor quality increased difficulties even further. Therefore there was a need to supplement the previously used accounting system with new process and external customer cost analysis. Two alternative approaches were developed to tackle the previously mentioned problems: the business process improvement approach and the natural work team approach. (Harrington. 1999, p.225)

A major breakthrough occurred in early 1990s as BPI methodologies (process redesign and process reengineering) and activity based costing accounting methodology were developed. That time COPQ – systems were used mainly to measure output error detection and correction. However, most of organization’s internal costs are non-value-added costs. Therefore there was a need to implement a term of non-value-added cost to the COPQ-methodology with two subcategories that are: business-value-added cost and no-value-added cost. (Harrington. 1999, p.225)

Quality costs-model supplements and supports total quality control, TQC philosophy as these both are striving to find a solution for poor quality and to improve productivity. TQC is a collection of methods for economically manufacturing products or providing services that meet quality requirements of a buyer (Kanatsu.1990, p.17-18). Quality costs provide the common economic denominator that can be utilized to communicate clearly and effectively in business terms. Quality costs can be used in quality programs to help evaluating in terms of cost improvement, profit enhancement and other benefits (Feigenbaum.1991, p.109-110). In the other hand one of the COPQ-system's purpose is to help achieving the minimum operating costs at the desired quality level. It was mentioned previously that COPQ-system is only one of the systems that help to achieve this particular objective however the multiplicity of COPQ-system need to be noted (Feigenbaum.1991, p.130). Feigenbaum.1991, p.130-131 has described the qualities and applications for use to COPQ-system serves as:

- A measurement tool.
- A process-quality analysis tool.
- A programming tool.
- A budgeting tool.
- A predictive tool.

2.3 Why to use COPQ?

Why understanding the elements of costs of poor quality is useful for a company? The goal of any COPQ-system is to enhance quality improvement efforts that will lead to operating cost reduction opportunities. In other words quality cost systems aims to make it possible producing high quality products with lower costs (Sissonen. 2008, p.40-41). The main objective of quality cost system is to find areas of improvement where quality costs can be achieved (Chopra & Garg.2011, p.512). For many factories quality costs represent 25 % or even more of factory costs in contrast productive labor is probably under ten percent of factory costs (ASQC Quality Costs Committee.1989, p.310). Every dollar saved in the total cost of quality has a direct impact on profit (ASQC Quality Costs Committee.1987b, p.3). Abdul-Rahman et al.1996, p.48 also supports previous way of thinking as the reduction in the cost of non-conformance is a popular motive for quality cost implementation since those lead to enhanced profit competitiveness advantage (Abdul-Rahman et al.1996, p.48).

Cost of poor quality is used as a management tool and it is a good indicator of the economic health of the organization as assessing quality costs can be regarded as a measurement of a company's performance regarding the process in which a product is being manufactured or a service is being delivered. In other words COPQ-level is one of the only measurements that can be used to evaluate the general quality level of large multinational corporation or its division (Miguel & Pontel.2004, p.309; Chopra & Garg.2011, p.511). Quality cost measures reveal shortcoming in i.e. in cost allocation, standards, procedures and practices that could have been remained undetected by the other analysis (Chopra & Garg.2011, p.511).

Cost of poor quality provides a useful tool that can change the way management and employees think about errors. According to Harrington 1999, p. 229 cost of poor quality system helps organizations by:

1. Quality information presented in currency helps management to relate to the problem and therefore it is easier to get management's attention. It translates quality out of abstract and makes it a reality that can effectively complete with cost and schedule.
2. COPQ-system helps to change the way employees think about errors: understanding the cost of errors they make will have greater impact on employees' future performance when compared to situation in which all the defected materials are only scrapped.
3. COPQ can be used to identify opportunities and to help to prioritize those opportunities and to set target and measure progress. Therefore it provides a better return on the problem solving efforts as the corrective action can be directed at the solutions that will bring maximum return.

4. It provides a mean to measure the true impact of corrective actions.
5. COPQ provides a simple, easily to understandable method of measuring what effect poor quality has on the organization.

2.4 COPQ Limitations

ASQC Quality Costs Committee.1989, p.129 emphasizes that quality costs can be used only for overall planning and control of a quality assurance program. Quality costs reports do not provide all-inclusive information and suggest directly specific actions that would quality costs. However, industrial engineers, quality assurance personnel and product personnel must use less aggregated data from COPQ-system to guide the company making appropriate actions reductions costs of poor quality (ASQC Quality Costs Committee. 1989, p.129). Therefore COPQ-system cannot resolve quality problems or optimize quality system by itself. It is only a tool that helps management to understand quality problems and underlying costs. It pinpoints opportunities for improvement and measures the progress of the improvement activities. Therefore COPQ system needs to be accompanied by an improvement process that reduces the errors being made (Harrington. 1999, p.229; Harrington.1987, p.8-9.) According to Campanella.1999, p.XV information from COPQ-system needs to use to "identify improvement projects, establish clear responsibilities, provide resources to diagnose and remove causes of problems and take other essential steps". It can be therefore said that COPQ-system helps to improve the whole organization machinery to attack and reduce the costs of poor quality. Campanella's determination highlights that organization can achieve most effective efforts by ensuring that organization has ingrained in its operating principles the understanding that quality and costs are complementary and not conflicting objectives (Campanella.1999, p.xvii.)

According ASQC Quality Costs Committee.1989, p.130 five specific problems with COPQ reports should be noted:

1) Much of information is subjective. Information used might based on a rough estimate of the time devoted to each activity.

2) Some of the important costs might were not exploited in reports. Most significant costs of external failure are indirect costs such as the opportunity cost of lost sales. It is said to be almost impossible to identify and then calculate correctly or even estimate reasonable costs. Therefore some of the costs are always omitted from quality costs reports.
3) Evaluation and allocation of overhead costs may be inexact as those much more difficult to determine than prime costs.
4) Variation in activity may decrease the comparability of quality costs from different periods. Change in total quality costs might merely reflect to the equivalent change in production or sales volume. This problem can be overcome by comparing quality costs from different periods on the basis of some activity measure such as their percentage of direct labor or direct material costs.
5) It takes time to influence on the quality costs and therefore effort and accomplishment are probably not matched in a single reporting period. Therefore too much emphasis should not be given to individual reports as results could be counter-productive.

3 OVERVIEW OF QUALITY COSTING MODELS

It is quite difficult for many to address what the true costs of quality are. The terms used by most quality professionals can be foreign to management and are difficult to summarize in an organization wide unit of measure that can be used effectively by management. Therefore cost of quality and cost of poor quality need to be translated to common denominator – money – to manage business. (Harrington. 1999, p.221)

To solve the problem of “cost of poor quality” Dr. Armand V. Feigenbaum developed a dollar-based reporting analysis in 1943 (Harrington. 1999, p.221-222) and presented the P-A-F cost model in 1956. Prevention – Appraisal – Failure (PAF)-model has been a cornerstone in quality models and it has been refined and expanded over the years so that today it a management tool that can be used to direct quality-improvement activities and measure the effectiveness of the total quality system (Harrington. 1999, p.221-222; Fransson & Turesson.2009, p.19).

It seems that advocates have no consensus about the content and scope of cost of poor quality measures. Cost of poor quality measurement method presented by Harrington 1987, p.13 consist of two major cost poor quality categories that are “direct cost of poor quality” and “indirect cost of poor quality”. Many quality cost models seems to focus completely on direct costs of quality as determination of measurement object can be done in the way that the results reflects to the actual costs. However, indirect costs of poor quality will supplement although it is relative hard to determine the actual costs of indirect poor quality costs.

3.1 PAF-model

Feigenbaum.1991.p.110-111 refers to direct quality costs as operating costs. According to his determination these operating costs mainly are mainly composed of cost of control and cost of failure of control (figure 5). Cost of control consists of prevention costs and appraisal costs and cost of failure of control consist of internal failure costs. It needs to be noted that Feigenbaum highlights that there are other costs of poor quality than operating quality costs which this particular model do not take in account. (Feigenbaum.1991, p.110-111).

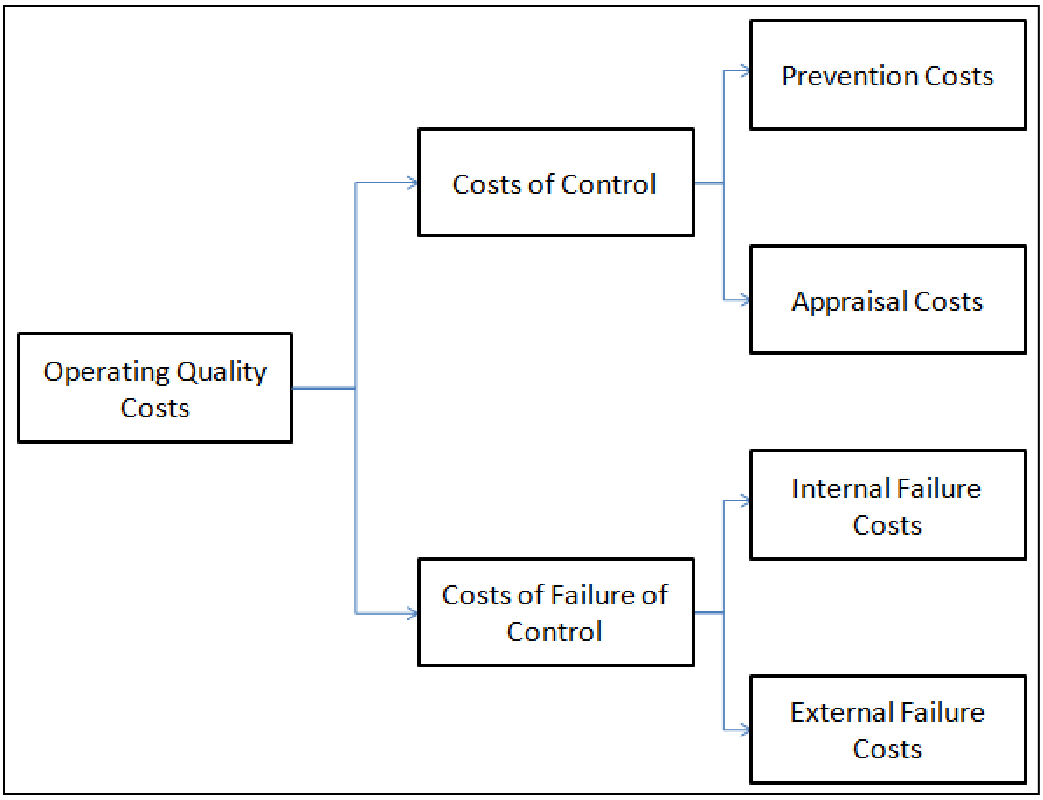


Figure 5. Operating Quality Costs. (Feigenbaum.1991, p.110-110)

This particular quality cost model can be classified as classic Prevention – Appraisal – Failure model as it consist completely on those items (Fransson & Turesson.2009, p.19-21). Also Crosby's conception of quality cost model is based on PAX-model. However there is a slight distinct as Crosby defines that cost of quality consists of cost of quality and cost of poor quality. Prevention and appraisal activities enable good quality and therefore those items belong to that sector. In the other hand poor quality is seen in failure explicitly in internal failures and external failures (Sissonen.2008, p.41 ; Fransson & Turesson.2009, p.21). Figure 6 illustrates content of Crosby's of quality cost model.

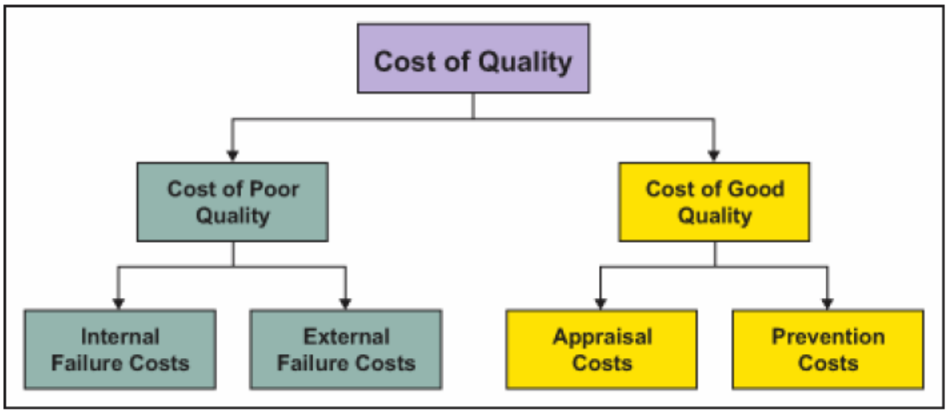


Figure 6. Components of quality costs.(Sissonen. 2008, p.41)

Quality cost model presented by Harrington's is also mainly based on PAF framework but it extends the scope of the model. According to Harrington direct cost of quality consist of three major types of expenditures: controllable COPQ, resultant COPQ and equipment COPQ. According to Harrington any company is able to control its prevention and appraisal activities and therefore the related costs depended on company's activities. In addition to these activities that are directly linked to quality control activities Harrington highlights non-value added costs that derive from activities that are needed in quality control but those are not directly directed into quality control activities (Harrington. 1987, p.13; Harrington.1999, p.227). Also Feigenbaum.1991, p.135 supports the importance of non-value added costs but does not classify those costs to be part of operating costs. Resultant costs of quality that are internal and external failure costs are functions of how well company has taken care of its controllable quality cost activities. In addition to controllable cost of quality and resultant cost of quality Harrington and Feigenbaum accentuate the importance of equipment quality costs (Harrington. 1987, p.13; Harrington.1999, p.227; Feigenbaum.1991, p.136-137). Following listing illustrates Harrington's quality cost model:

Direct poor-quality cost.

(1) Controllable poor quality cost:
   - Prevention cost.
   - Appraisal cost.
   - Non-value-added cost.

(2) Resultant poor quality cost:
   - Internal error cost.
   - External error cost.

(3) Equipment poor quality cost.

In the general model for evaluating cost of poor quality presented by Camal & Elshennawy.2004, p.291 the cost of conformance is made to include two functions: the cost of maintaining stable operation at existing level of conformance (   ) and the cost of improving operation (   ). As the purpose of this paper is to evaluate the cost of nonconformance at existing quality level the determination of latter is excluded. The costs of maintaining stable operation at stable level can be also termed as reactive costs. According to Camal & Elshennawy.2004, p.291 these costs include following:

- The costs of monitoring the state of operation (   ).
- The costs of inspecting production units (   ).
- The costs of deviating from performance targets (   ).

It needs to be noted that when comparing this particular cost of poor quality model with the previous models there are many similarities. The cost of monitoring and cost of inspecting production units can be referred as appraisal costs. And the costs of deviating from performance targets can be seen as cost of failure costs including internal and external costs. However, this particular definition seems to lack of costs of prevention activities. According to Camal & Elshennawy.2004, p.291 the total reactive cost per unit time of operation can be evaluated adding above elements together.

As seen from below table 2 that summarizes different direct quality cost models that quality cost model presented by Harrington in year 1999 is the most extensive and it includes all the other quality cost models. Therefore this paper discusses about direct quality costs using Harrington's model as a framework. Extent of direct quality costs is extremely wide as Camal & Elshennawy.2004, p.291 present a that direct cost of poor quality elements including 101 prevention costs, 73 appraisal costs, 139 internal failure costs and 50 external costs (Camal & Elshennawy.2004, p.2004). The most important of those are presented in appendix 2.

Table 2. Summary of direct Quality Cost Models.

	Feigenbaum 1956	Crosby 1980	Feigenbaum 1991	Harrington 1987	Harrington 1999
Prevention cost.	x	x	x	x	x
Appraisal cost.	x	x	x	x	x
Non-value-added cost.			x		x
Internal error cost.	x	x	x	x	x
External error cost.	x	x	x	x	x
Equipment poor quality.			x	x	x
Customer-incurred cost.				x	x
Customer-dissatisfaction cost.				x	x
Loss-of-reputation cost.				x	x
Lost-opportunity cost.					x

3.1.1 Controllable COPQ

Management has direct control on controllable cost of poor quality in terms that only customer-acceptable products and services are delivered to the customer (Harrington.1987, p.14). According to Harrington 1999, p.224 controllable costs are divided even further into three elements that are prevention costs, appraisal costs and non-value-added costs.

Prevention costs

Prevention costs are the costs of all activities expended to prevent errors being made in products and services (Harrington.1987, p.14; Crosby.1980, p.105; Campenella.1999, p.5). In other words prevention costs include all the costs involved helping the employee doing the job right every time. In financial point of view prevention cost is not actual cost but an investment in the future. According to Sissonen.2008, p. 45 examples of prevention costs includes the costs for quality planning, supplier evaluation, new product review, mistake-proofing, process capability evaluations, quality improvement team meetings, quality improvement projects and naturally also quality education and training. Crosby.1980, p.4 continues that fact of life is that each year costs of sales in many companies rises faster than their prices. Therefore there is a remarkable need to eliminate or reduce costs in order to make a profit. This highlights the significance of defect prevention in cost reduction as best single way to do to reach that goal.

The best way a company can spend its poor-quality investments is to invest in preventive action as previously mentioned the "1-10-100 Rule" suggest. However these preventive actions on poor quality are commonly neglected because it is difficult to tie it to a tangible return on investment (Harrington.1987, p.15.) Increase of preventive activities reduces the total amount of errors. Therefore the costs related to total errors are reduced. Following figure 6 illustrates the effect of prevention cost on the total number of errors on the left side of the picture and the total error cost on the right side of the picture (Harrington.1987, p.17-18.)

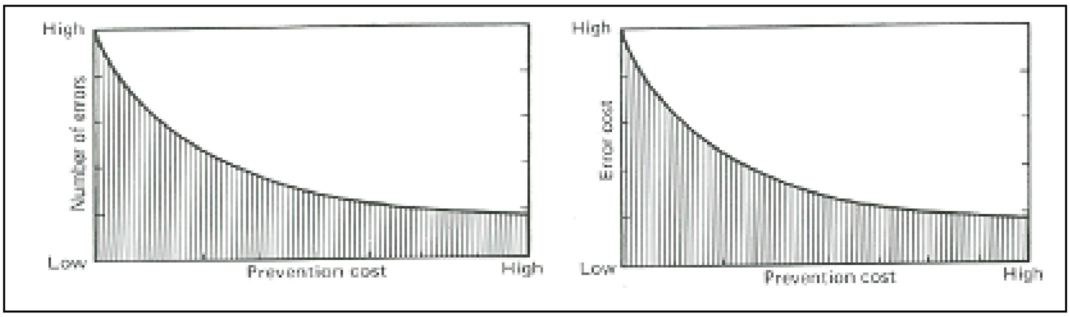


Figure 7. Effect of prevention costs on the total number of errors and the total error costs. (Harrington.1987, p.18)

As left part of above figure 7 illustrates, prevention costs decreases as number of errors goes down. In addition in simultaneously error costs of all errors made by organization goes down will also the prevention costs decrease as it is shown in right part of figure.

Appraisal costs

Appraisal costs are all the costs used to evaluate if already completed activity was done the right every time (Harrington.1987, p.15-16; Crosby.1980, p.105; Campanella.1999, p.5). Appraisal costs occur mainly because of the need to ensure high quality level for customers (Sissonen.2008, p.46). According to Sissonen.2008, p.46 appraisal costs include: checking and testing purchased goods and services, in-process and final inspections and tests, field testing, product, process and service audits, calibration of measuring and test equipment.

Harrington.1987, p.16-17 notes that the only reason appraisal costs are needed is because management is not confident that prevention actions on poor quality are 100% effective at eliminating the possibility of an error. As prevention cost prevents errors to occur in the first place, appraisal costs prevent possible errors to be delivered to inner or external customer.

Crosby.1980, p.19 determines that quality management is a systematic way guaranteeing that determined activities take place as planned. This determination highlights the significance of quality management in terms of preventing problems from occurring by creating the attitudes and controls that make prevention possible. (Crosby.1980, p.19)

Figure 8 illustrates effect of appraisal cost in two situations. The first situation (right part of the picture) illustrates total number of errors and total error cost when internal and external errors are equal. The second situation (left part of the picture) illustrates the effect of appraisal costs on total number of errors and total error cost when external error cost is two times internal error cost. (Harrington.1987, p.19-22)

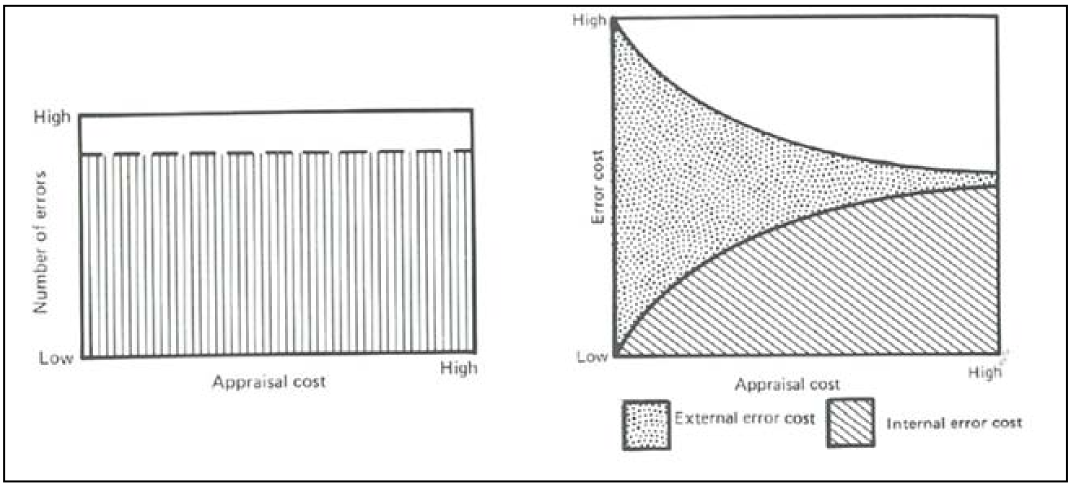


Figure 8. Appraisal costs (Harrington.1987, p.22)

Using the information from above figure 7 it can be proven that appraisal actions made to lower overall cost of poor quality have a significant effect even if the cost of external cost is only two times higher than internal cost. As per "1-10-100 Rule" that can be used as rule of the thumb suggest that actually external costs are significantly more expensive than internal costs. Therefore the actual effect of appraisal actions is even more remarkable.

Non-value-adding costs

According to Campanella.1999, p.XV quality costs have been traditionally emphasized the costs of non-conformances. There is however a need to expand the scope of quality costs to include estimation the costs of inefficient processes. In other words cost of poor quality should include non-value adding operations such as redundant operations and sorting inspections.

Risk with COPQ-system according to Crosby.1980, p. 104 is that managers try an endless list of classifications of things that should be taken into calculations when calculating cost of poor quality. Therefore the problem seems to be that managers are too keen in acquiring all the information in order to obtain an exact cost figure without understanding the reason for doing the calculation in the first place. Crosby continues by highlighting that the purpose for the COPQ-program is to get management's attention and to provide a measurement base for quality improvements and for cost reduction. Therefore it seems to be more appropriate to have a COPQ system that might not take in account all the costs but it is simply, usable tool that can be used to set reduction objectives.

It is rare that determination of cost of poor quality would go so far as to identify costs of poor quality down to the level of a secretary correcting a letter containing a mistake and therefore lot of elements of costs are overlooked mainly because most accounting systems are not designed to identify those actions as cost of poor quality. Because of management is overlooking hidden costs the interrelationship of quality schedule and costs is likely to be unbalanced in favor of schedule and cost at the expense of quality. This imbalance exists as long as real cost of quality remains hidden among total costs of quality. These hidden costs of cost of poor quality can be determined by using the iceberg model. According to Campanella these hidden costs might present major deal of total costs of poor quality and therefore those need to be taken in account in COPQ-system as what is being measured can be improved. According to Campanella's findings it seems that those are opposite to Philip Crosby's findings that took place in 1980 and in which the purpose was not to concentrate on the true failure costs that includes all the hidden costs but only acquire appropriate amount of information to start the cost of poor quality program. (Campanella.1999, p.5-6)

Many Finnish companies estimate their level of "cost of poor quality" only based on most concrete "here and now" costs without even trying to estimate the hidden costs. Therefore these companies miss opportunities of reducing costs that they are not measuring (Sissonen.2008, p.43-44). Iceberg model can be used to illustrate that most of the elements of cost of poor quality are hidden and therefore those are hard to identify by formal measurement systems. The iceberg model, presented in figure 9, compares the true failure costs to an iceberg with commonly measured costs of poor quality as the “tip of the iceberg” as most of the costs are hidden below the surface. Only a minority of the costs of poor and good quality is obvious and they appear above the surface of the water as can be seen from the figure (Campanella.1999, p.7).

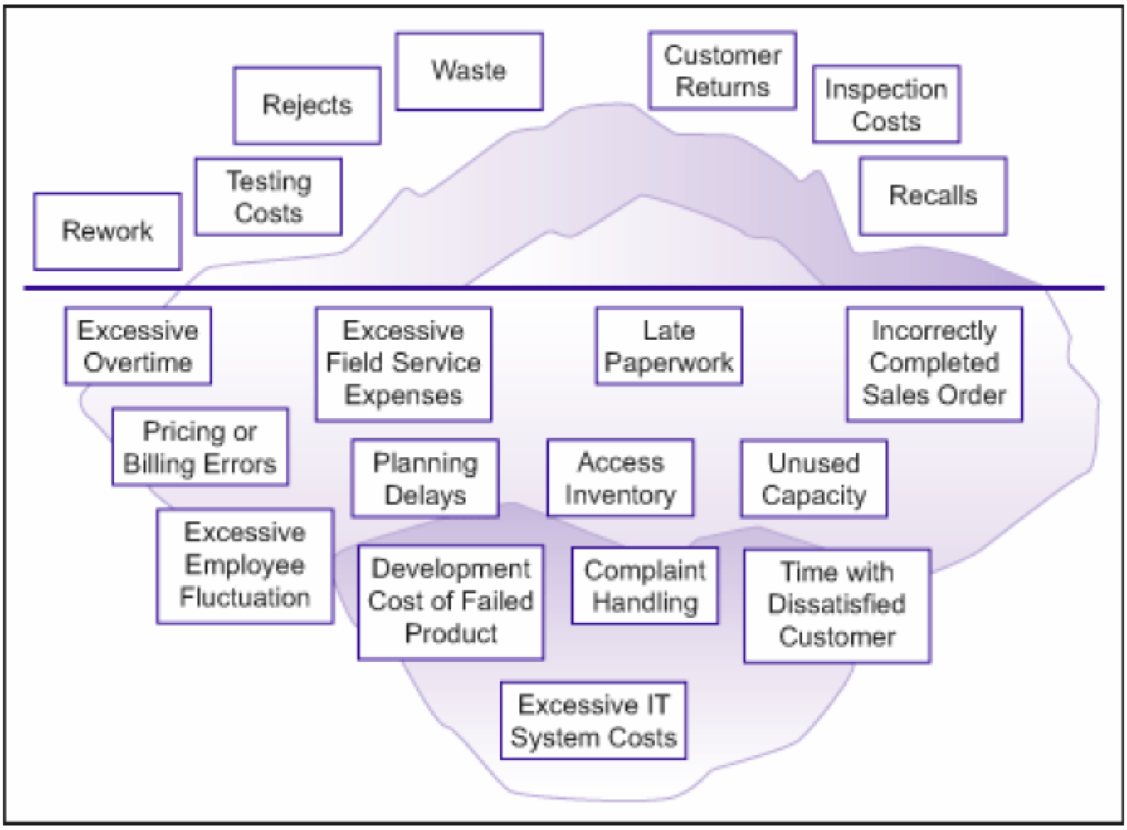


Figure 9. The iceberg model of cost of quality (Sissonen. 2008, p.44)

A danger lies in finding and collecting only a small portion of costs that are involved and using this amount as total costs of poor quality. There are no model existing that would determine all the hidden costs in general but people in organization need to use their imagination to find these costs of inefficiencies. These costs of inefficiencies are buried in the same way that other real costs of poor quality are buried as they are handled as accepted costs of doing business. If management would have all the information about these hidden costs, it would allow company to reduce these measured costs significantly. (Campanella.1999, p.6-7)

However it is hard, if not impossible to place a dollar value for hidden quality costs. Therefore these hidden quality costs are also referred as intangible costs of poor quality. However some companies have found “multiplier effect” when studying failure costs and true failure costs. According to Westinghouse Electric Corporation the true costs of poor quality of quality can be calculated using at least three or four times higher hidden costs than commonly measured cost of poor quality. (Campanella.1999, p.7)

Campanella.1999, p.15-16 continues that in case that hidden and indirect quality costs are incurred but not accurately identified within the cost accounting system, estimates of these costs should be used until the system can be adjusted. The use of estimations of hidden and indirect costs will be necessary before reasonable picture of total quality costs can be portrayed. Campanella highlights the need to have all the quality related elements visible so that they can become a target for cost reduction.

3.1.2 Resultant COPQ

Resultant cost of poor quality is the second element of direct COPQ category. These costs are directly related to management decisions made in the controllable cost of poor quality. Resultant costs include all the company-incurred costs. In other words resultant cost includes all the money spent because of activities were not done right every time. Resultant cost of poor quality is divided into two categories that are internal costs and external costs. The common factor for these two subcategories is that these costs could appropriately be called losses as these are direct losses to the company. (Harrington.1987, p.23)

Internal costs

All the costs that are incurred by the company as a result of errors detected before the output is accepted by customer are internal costs. Internal costs include the costs incurred from the time an item is shipped from a supplier until it has been accepted by the customer. In other words internal costs are caused because products or services do not conform customer requirements but the faults are found before delivery of product and services to external customer. If these faults would have not been found in-house would mentioned products and services led customer not being satisfied and therefore caused external failure costs (Harrington.1987. p.23; Campanella.1999, p.5). Deficiencies can be both caused both by errors in products and in services but also in processes (Sissonen.2008, p.46). According to Sissonen.2008, p. 46 typical forms of internal failure costs are:

- Scrap.
- Rework.
- Reinspection.
- Retesting.
- Material review.
- Downgrading.
- Delays and shortages.

External failure costs

In traditional quality cost systems, external failure costs are the most obvious and thus easiest to measure and monitor (Sissonen.2008, p.46). External costs are incurred when unacceptable product or service is delivered to external customer. In other words prevention system has failed to produce customer-acceptable product or service and this defected output was failed to detect by appraisal system before it was delivered to customer Harrington.1987, p.24; Campanella.1999, p.5). According to Sissonen.2008, p.46 examples of external costs include the costs for: complaints, product recalls/ repairing goods and redoing services, warranty claims, customers' bad will, losses due to sales reductions, external failure costs are the most expensive ones to correct and thus prevention of mistakes beforehand is much more preferable than correcting afterwards.

3.1.3 Equipment COPQ

The last element of direct cost of poor quality category is equipment COPQ. It contains all the investments in equipment that are used to measure, accept, or control the product or service, together with the related equipment amortization. In addition, also cost of building and cost of occupied floor space can be part of equipment COPQ in case that major testing is needed (Harrington.1987, p.25; Feigenbaum.1991, p.136-137). However, equipment COPQ does not include any equipment that are used to produce products or computing system that are used for accounting and scheduling (Harrington.1987, p.25).

Cost of equipment is invested to prevent quality failures and in order to obtain economies in appraisal activities and costs include measuring equipment such as inspection and test machines, process quality-control devices and quality information data processing computers. When these costs are first identified and then added to COPQ-calculations, these will together give more accurate and complete picture of effectiveness of total quality system. (Feigenbaum.1991, p.137)

Equipment utilization used to represent smaller element in quality cost improvement and therefore it was considered as side cost of business and not as integral part of COPQ-system. Today, however, equipment quality cost has become essential part as company equipment investment is becoming larger as importance of good quality results grows. One of the main reasons for increasing importance of equipment COPQ concerns the growing utilization of automatic test equipment (ATE) in quality programs as it has exponentially increased potential effect of upon quality cost improvement. (Feigenbaum.1991, p.137)

3.2 Economics of direct Quality Costs

According to Superville & Gupta.2001, p.420 there is consensus among academics that investment in quality programs provides a high rate of return. However there is disagreement on how the optimal level of quality investment can be modeled. Some of the academics also believe there is no correct cost of quality model as costs related to quality are dynamic and firm specific. Feigenabaum.1991, p.110-112 continues that determination cost of control and cost of failure of control contains key costs associated with quality and these embrace the achievement of such features as reliability, safety, maintainability and other relevant quality characteristics.

The objective of any quality programs should be finding the defect rate that minimizes the total cost of quality. According to the previous discussion it was understood that this would be attained at 100 % conformance rate. However some nonconformance still exists at that level. These costs depend on company's operating conditions and type of business objectives. Therefore those costs are different for different companies (Superville & Gupta.2001, p.420). ASQC Quality Cost Committee.1989, p.127 continues that it is important to understand how elements of direct cost of poor quality interact with one another before COPQ system is embarked. However it need to be noted that quality relationships are dynamic rather than static as the by the time there is sufficient amount of information accumulated to determine these relationships it is more than likely that the conformity has changed (ASQC Quality Costs Committee.1989, p.127). Harrington.1987, p.39-43 has made couple of important findings when studying connection of controllable and resultant costs. Harrington had two simulations when studying this connection. In the first simulation, major expenditures took place in appraisal activities and in the second simulation expenditures increased in prevention activities. In the first simulation internal costs increased as appraisal costs increased but the increase is more than balanced by the decrease in external error costs (figure 10).

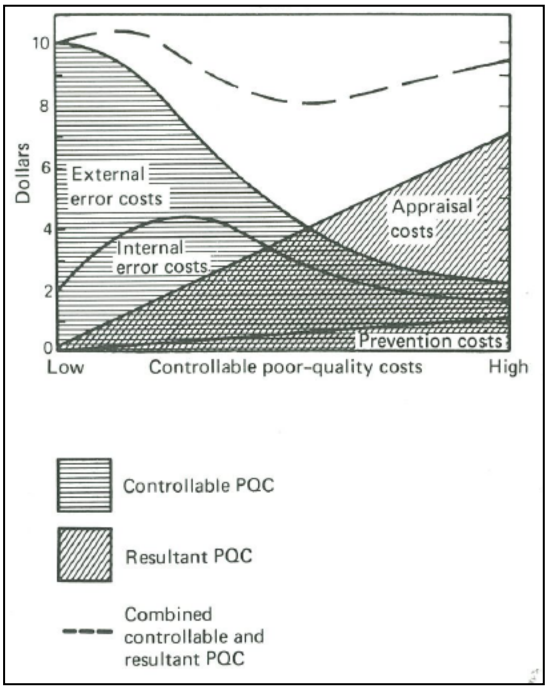


Figure 10. Effect of varying controllable COPQ. (Harrington.1987, p.30)

The result of the second simulation is that the increase in prevention costs decreases both internal and external error costs. In addition, appraisal costs can be decreased as inspection levels can reduced because the quality has been improved and less inspection time is required to re-inspect rejected outputs as fewer outputs are rejected (figure 11).

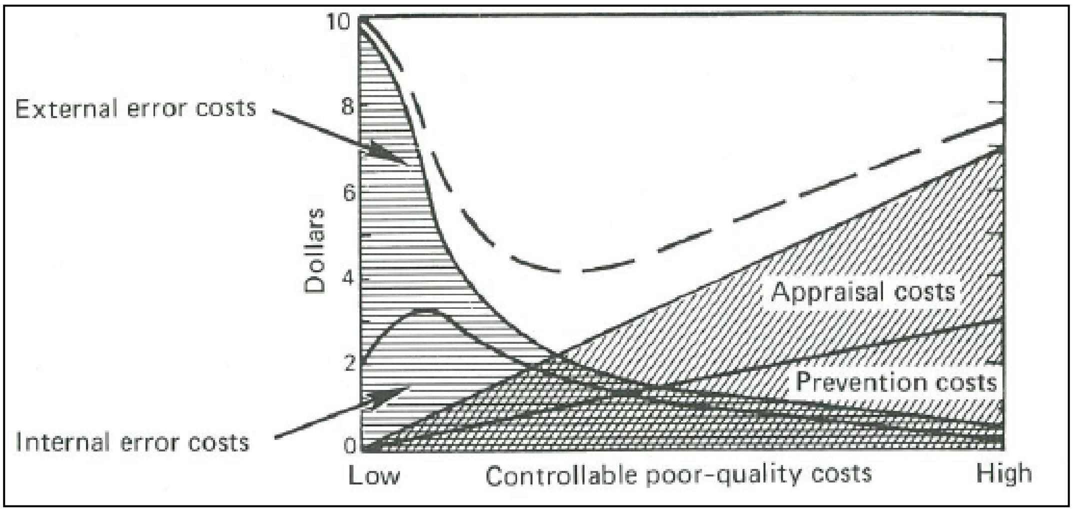


Figure 11. Increased expenditures in prevention activities. (Harrington.1987, p.41)

Based on the findings of previous paragraph it seems that companies ought to increase their prevention expenditures at expense of appraisal expenditures as prevention costs have greatest return (Harrington.1987, p.43-44; Superville & Gupta.2001, p.421). However, these two elements of controllable COPQ interact with each other (Harrington.1987, p.43-44). Increase in prevention costs in terms of right kind of system engineering work in quality control reduces the number of defects in outputs and also prevents non-conformities from occurring. This reduction allows remarkable reduction in failure costs but it also makes it possible to lower appraisal costs as defect reduction means a reduced need for routine inspection and test activities (Feigenbaum.1991, p.112-114). It should be noted that prevention activities are more difficult to implement than appraisal activities as those require vision, innovation, and break from status quo. The results of prevention activities may also not be immediately measurable. If quality problem cannot be prevented it should be detected. (Superville & Gupta.2001, p.421-422). Efficient appraisal activities in terms of better inspection and test equipment enable efficient process-control that is important as it has a positive downward pull on the costs of the appraisal costs but it also enables root cause analysis (Feigenbaum.1991, p.112-114). Therefore a comprehensive program of error prevention and corrective action must parallel the appraisal activities at the same time in order to make sure that maximum use is made of data collected during the appraisal operations. This combination of prevention and appraisal operations puts into motion a complementary cost-reduction system in which errors are systematically tracked down and action is taken to prevent them from occurring. As a result error level decreases and there are fewer problems needed to be solved. This allows cutbacks in prevention costs and appraisal costs as the figure 12 is illustrating. (Harrington.1987, p.43-44)

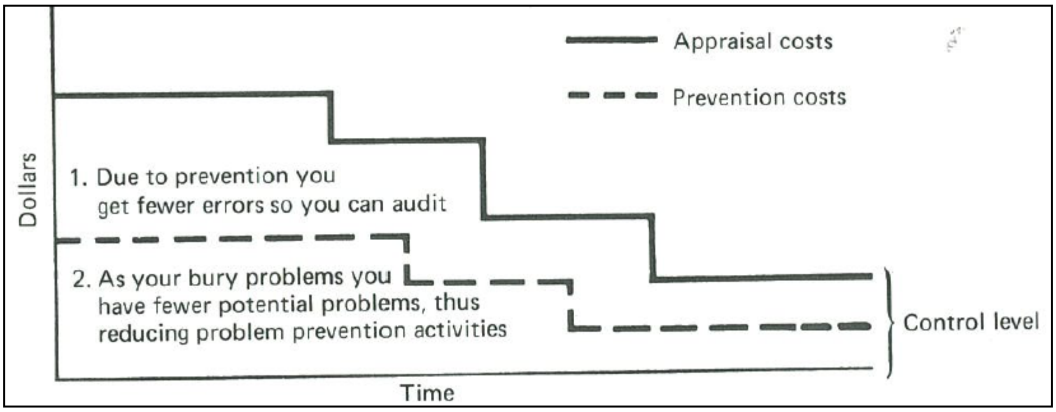


Figure 12. Prevention/appraisal interaction. (Harrington.1987, p.40)

3.3 Quality Loss Function, QLF

Can indirect and hidden costs of poor quality be quantified? According to Campanella.1999, p.13-15 there is a need to approximate these long-term and hidden costs as they are the largest contributor to total quality loss. Dr. Genichi Taguchi has created the Quality Loss Function (QLF) for the purpose to reflect not only immediate costs but also long-term losses as well (Campanella.1999, p.13-15).

QLF addressed quality both in off-line and in on-line quality control. Off-line quality can be defined as improvements in quality in the product and process development stages and on the other hand on-line quality is determined as monitoring actions taken in order to verify the quality levels (Jeyapaul et al.2004, p.1331). Quality Loss Function extends the zero defect standards with the introduction of the robust quality standard. This particular methodology shifts the focus of quality control from conformance quality to quality of design. The most important message in QLF is the ideology that loss of poor quality is incurred when quality deviates from the target value. Taguchi also insisted the actual loss of quality is always greater than it is expected to be as most evaluations of cost of poor quality do not concern hidden quality cost that can in most cases be higher than conventional costs of poor quality as iceberg model of quality costs claims. Thereby the robust design of QLF is developed in order to capture not only direct but also hidden costs of poor quality (Cheah et al.2011, p.408). The robust design of QLF is an engineering method of quality improvement that seeks to minimize total costs including manufacturing costs and quality loss cost (Cao et al.2004, p.101; Jeyapaul et al.2004, p.1331). According to Jeyapaul et al.2004, p.1331-1332 this optimization is based on following three stages:

1) Concept Design or System Design.
2) Parameter Design.
3) Tolerance Design.

The concept of design is the first phase of design strategy. It gathers the technical knowledge and experience so that designer can select the most appropriate system design for intended product or process. The purpose of parameter design is to define the control factors. This particular phase does not affect the manufacturing cost of the unit. The phase of tolerance design can be only started after the parameter design phase is completed. It focuses trade-off between quality and cost. The possibility of tightening of tolerances, material standards and components upgrading need to examined in this particular stage in case those have a significant impact on quality through the selected quality parameter (Jeyapaul.2004, p.1331-1332).

The design of QLF methodology links product performance requirements and the production process in a way that it relates closely with product quality and cost. QLF suggests that tolerance ought to be determined by trading off quality loss and cost by applying quadratic loss function (Cao.2004, p.101). QLF method is designed in a way that it can be used in cases where there is only one quality variable (Jeyapaul et al.2004, p.1331). According to Campanella.1999, p.13-15 the way the QLF is established depends on involving type of quality characteristic that is whatever is measured to judge quality performance. According to Campanella.1999, p.13-15 different QLF functions can be created when divided quality characteristics into three categories:

1) Nominal-the-best
2) Smaller-the-better
3) Larger-the-better

Nominal-the-best

Nominal-the-best (NTB) quality characteristic should be used when quality-wise purpose of the output is to achieve desired target value with minimal variation. Dimension and output voltage are good examples of nominal-the-best quality characteristic. When using this quality characteristic, loss occurs not only when a product is outside the specifications, but also when product falls inside the specifications. According to Taguchi's determination the loss continually increases as a product derivates further from the target value as it is illustrated in following figure 13. (Campanella.1999, p.13-14)

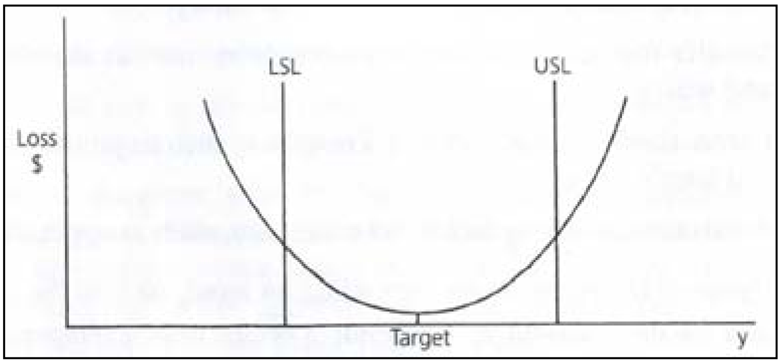


Figure 13. The Quality Loss Function. (Campanella.1999, p. 14)

The cost curve of QLF is quadratic in nature so the costs of poor quality also increase by the square of the distance as moving away from target value. Therefore, if the deviation is doubled, the loss is quadrupled (Campanella.1999, p.14).

According to Cao et al.2004, p.101 the QLF presented by Taguchi can be calculated by using following formula:

, in which
L = Loss in $’s
k = Cost coefficient
y = Value of quality characteristic
= Target value for quality characteristic

According to Cao.2004, p.101 when assuming that tolerance of dimension *y* is *T*, and the loss of failure is *A*, the positive cost coefficient *k* can be determined using following formula:

$$—$$

According to Cao et al.2004, p.101-102 the target value for quality characteristic and tolerance T are often determined based on some hypothesis and approximations or in some cases engineering application experiences (Cao et al.2004, p.101-102).

Smaller-the-best

Smaller-the-best (STB) quality characteristic should be used when ideal target value is defined as zero. Minization of heat exchanger is a good example of smaller-the-better quality characteristic. According to Taguchi’s determination a more desirable product can be produced by minimizing this characteristic as much as possible as loss continually decreases as quality character is moving towards zero-level (figure 14). (Open Textbook of the University of Michigan Chemical Engineering Process Dynamics and Control. 2006)

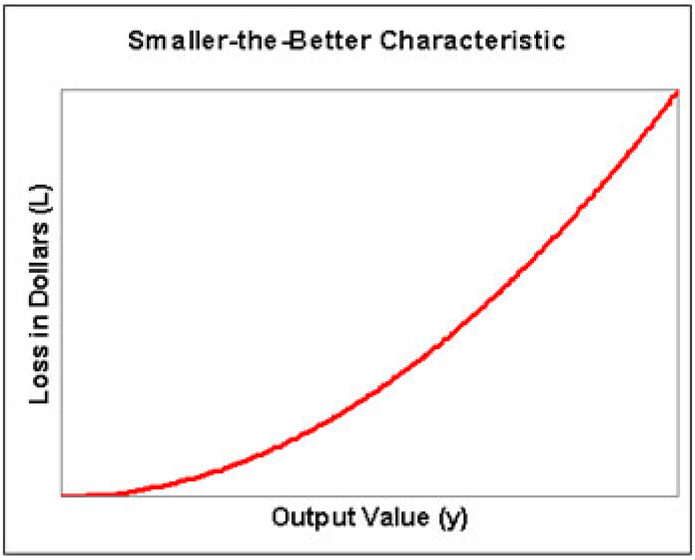


Figure 14. QLF with smaller-the-better characteristic (Open Textbook of the University of Michigan Chemical Engineering Process Dynamics and Control. 2006)

Above Figure of QLF with smaller-the-better characteristic illustrates that the quality loss is minimized as the output value is minimized. According to Open Textbook of the University of Michigan Chemical Engineering Process Dynamics and Control. 2006 QLF with smaller-the-better characteristic can be calculated with following equation:

, in which
L = Loss in $'s
k = Cost coefficient
y = Output value of quality characteristic

Cost coefficient *k* can be determined for smaller-the-better quality loss function followingly:

— , in which

A_0 = Consumer Loss in $'s

y_0 = Maximum Consumer Tolerated Output Value

Larger-the-better

Quality loss function with larger-the-better (LTB) quality character is opposite of smaller-the-better quality loss function and therefore the objective is to maximize the value of quality character. The ideal value for quality character is infinity as moving towards infinity will continually decrease related quality losses. Maximizing product yield from a process is a good example of larger-the-better quality character (Open Textbook of the University of Michigan Chemical Engineering Process Dynamics and Control. 2006). It needs to be noted that quality characteristic such as non-defective product rate that have maximum possible rate of 100% are not larger the better characteristic as maximizing such characteristics do not lead to infinity. Hence, those should be calculated using Nominal-the-best characteristic (Sharma et al. 2007, p.219). A graphical representation of the Larger-the-Better characteristic is below (figure 15).

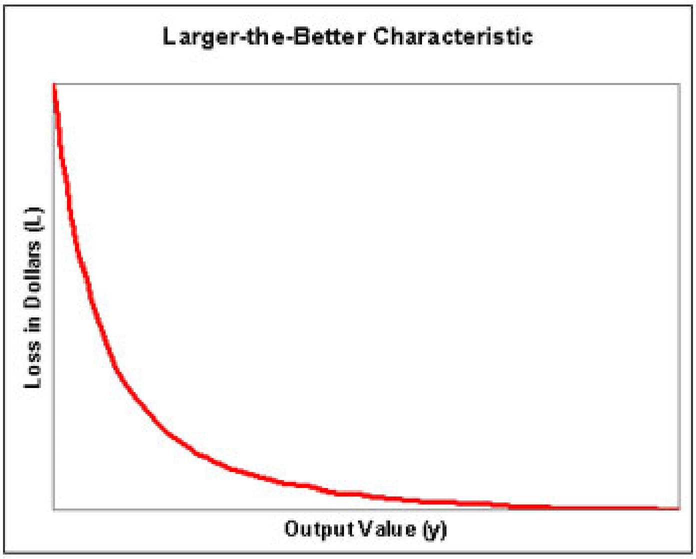


Figure 15. QLF with larger-the-better characteristic (Open Textbook of the University of Michigan Chemical Engineering Process Dynamics and Control. 2006)

Above Figure of QLF with larger-the-better characteristic illustrates that the quality loss is minimized as the output value is reaching infinity. According to Open Textbook of the University of Michigan Chemical Engineering Process Dynamics and Control. 2006 the equation used to describe QLF with larger-the-better characteristic of one unit of product:

— , in which

L = Loss in $'s
k = Cost coefficient
y = Output value of quality characteristic

Cost coefficient k for QLF with the larger-the-better characteristic can be calculated by using the equation given for the smaller-the-better proportionality constant. The difference between these two equations is that the definition of y_0 in larger-the-better quality character is minimum consumer tolerated output value instead of maximum consumer tolerated output value that is used in previous case. (Open Textbook of the University of Michigan Chemical Engineering Process Dynamics and Control. 2006)

Limitations of QLF

According to Cao et al.2004, p.101-102 and Jeyapaul et al.2004, p.1331 QLF has three limitations in practice:

1) Estimated quality loss is infinite.
2) In most cases the actual distribution of loss is asymmetrical.
3) QLF can be only used for single response cases.

Quality cost calculation example

Following example is chosen to demonstrate how to use statistical QLF function when calculating quality losses for product having NTB quality character. In this case company is producing a part having a hole measuring 0.5" ± 0.050". In addition company has investigated that quality costs for defected material is $45. These values are applied to determine value for cost coefficient. Using formula presented for NTB quality character cost coefficient k gets a value of 18 000 (Business Systems and Business Standards Discussions and Information Forum.2011).

In order to have required information available company measures dimensions of holes of 30 parts. Those values are presented in below table 3.

Table 3. Measured Values (Business Systems and Business Standards Discussions and Information Forum.2011)

0.459	0.478	0.495	0.501	0.511	0.527
0.462	0.483	0.495	0.501	0.516	0.532
0.467	0.489	0.495	0.502	0.521	0.532
0.474	0.491	0.498	0.505	0.524	0.533
0.476	0.492	0.500	0.509	0.527	0.536

It is obvious that all of these measured values fall within company's specifications but QLF methodology however suggest that these parts cause cost of quality as these is deviation from nominal value. The average point for measured values is 0.501 and standard deviation is 0.022. This information is applied when calculating total quality loss of the sample by multiplying the average loss of part by number of samples. When the average value of hole and standard deviation are applied together with cost coefficient determined earlier the average quality cost per part is $8.73 and hence the cost for total number of sampled parts is $261.90. (Business Systems and Business Standards Discussions and Information Forum.2011)

3.4 Indirect COPQ

Far too often business management base their decisions on the immediate impact they have on the business, but ignoring the impact these decisions have on their customers and the long range impact on the business itself (Harrington.1987, p.125). The other part of the COPQ system is indirect COPQ which is defined as those costs that are not directly measurable but they are part of the product life cycle COPQ. Indirect COPQ consist of four major elements that are: customer-incurred COPQ, Customer-dissatisfaction COPQ, Loss-of-reputation COPQ, Lost-opportunity PQC (Harrington. 1999, p.227-228). However, the indirect COPQ is important part of comprehensive COPQ-analysis, it is ignored by many organizations or it might have been part of considerations when organization is making a change in the appraisal activities (Harrington. 1999, p.227-228). Harrington.1987, p.131 highlights that dealing only with the direct COPQ can provide only part of the total picture that can be misleading as direct COPQ can be only fraction of indirect COPQ. According to Superville & Gupta.2001, p.421 these intangible costs are usually forgotten by company's management.

3.4.1 Customer-incurred COPQ

Harrington.1987, p.135 states that "Customer-incurred COPQ appears when an output fails to meet the customer's expectations. According to Harrington.1999, p.227-228 typical customer-incurred PQC are:

(1) Loss of productivity while equipment is down.
(2) Travel costs and time spent to return defective merchandise.
(3) Overtime to make up production because equipment is down.
(4) Repair costs after warranty period is over.
(5) Backup equipment needed when regular equipment fails.

It is necessary to apply COPQ to the impact that errors have on the customer. The cost incurred by the customer can far exceed the cost of repairing the defective item (Harrington. 1999, p.227-228). This is illustrated in Figure 16. Same figure also illustrates how customer-incurred costs decreases as the total number of errors decreases.

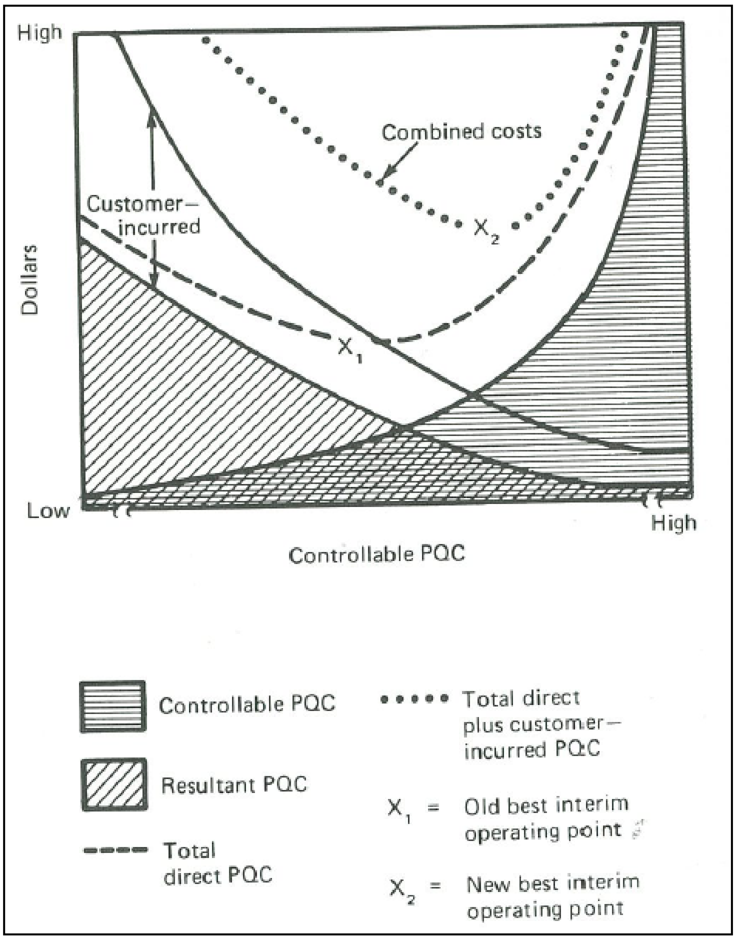


Figure 16. Customer-incurred COPQ (Harrington.1987, p.136)

Harrington. 1999, p.227-228 illustrates that customer-incurred costs can far exceed the internal costs of fixing the defected output by following consideration: “a ten-year-old boy who is delighted to find a new red and white bicycle beneath the Christmas tree. When he and his father try to assemble the bicycle, everything goes well until they attempt to put on the front wheel and find that a nut is missing. As a result, before the bicycle can be used, the father must make a trip to the bicycle store, wait in line to get a new nut, and return home ± a waste of one hour of valuable time and 24 miles of travel. The cost to the organization is a 5¢ nut; the cost to the customer is 300 times more.”

3.4.2 Customer-dissatisfaction COPQ

Harrington.1987, p.126 refers to The White House Office of Consumer Affairs reports, in which is presented that “96 percent of the unhappy customers never complain about discourtesies, but up to 81 percent will not buy again from the business that offended them. In addition, the average unhappy customer will tell his or her story to at least 9 other people and 13 percent will tell more than 20 people”.

Customers are either satisfied or dissatisfied – rarely a customer is in between. Therefore customer dissatisfaction is a binary thing. Figure 17 illustrates customer-dissatisfaction COPQ in terms of lost revenue versus product quality level. (Harrington. 1999, p.228)

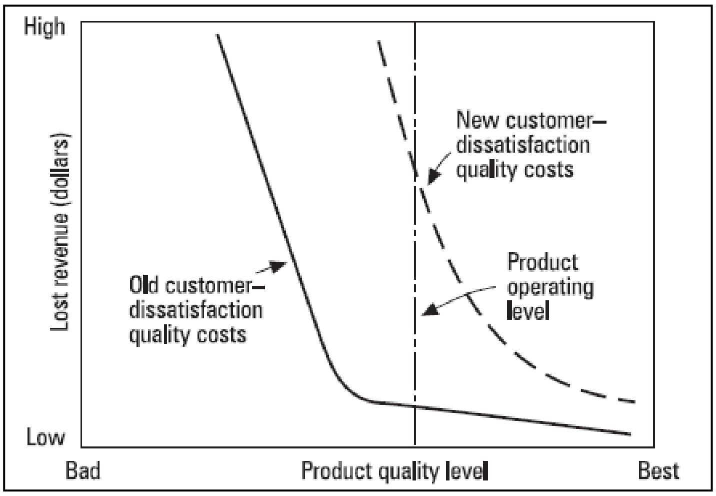


Figure 17. Changes in customer-dissatisfaction cost. (ASQC Quality Costs Committee.1987a, p. 411)

In the beginning small improvements in product or service quality will affect greatly on decrease of lost revenues. This sharp decrease in cost per small increase in product quality level reflects to the binary classification in the customer’s mind. This is illustrated by sharp decrease in lost revenues on left side of the curve in above figure 17 (ASQC Quality Costs Committee.1987a, p.410.) The curve becomes almost flat as customer’s acceptance level has been reached, however the product or/and service quality level continues to improve (Harrington. 1999, p.228.) Customer-dissatisfaction quality costs do not fall to zero as a small percentage of defected outputs can slip through most processes. Also human nature makes it certain that some portion of customers is always expecting more from a product that they are receiving. (ASQC Quality Cost Committee.1987a, p.410)

In addition to presenting the connection between the customer-dissatisfaction quality costs and product quality level, figure 17 also illustrates that customer satisfaction is not static but dynamic. Customer's expectations will change, and they are requiring better products and services to satisfy their demands and expectations. This is also illustrated in figure as expectation level will move from "old customer dissatisfaction quality costs" to "new customer dissatisfaction quality costs". (ASQC Quality Costs Committee.1987a, p.410; Harrington.1999, p.228.)

3.4.3 Loss-of-reputation COPQ

Loss-of-reputation is an indirect quality cost that is caused because customer dissatisfaction in company's one output will reflect to customer's attitude toward an organization rather than individual output. Therefore loss-of-reputation differs from customer-dissatisfaction as the purpose of loss-of-reputation COPQ is to measure and predict quality costs that are caused to whole organization rather than for one individual production line. This makes the evaluation, measurement and predicting much more difficult. The loss incurred due the loss of a good reputation cannot be imposed on an individual product COPQ curve but those costs must be considered as a total effect on all product lines. Therefore it is considered as a good business practice to group and distribute products under different trademarks based on expected performance. (Harrington.1999, p.228)

3.4.4 Lost-opportunity COPQ

Loss-opportunity COPQ relates to the revenue that the organization does not realize achieve because of the result of poor output or judgment. Loss-opportunity is caused because of actions taken by company that results customers to turn away form company's products to their competitors. In other words loss-opportunity COPQ examines the costs or in this case losses involved when company lose a customer. The determination of loss-opportunity COPQ is quite straightforward however the evaluation and measuring the actual poor quality costs are quite difficult to put into practice. However, evaluation for lost revenue and profits can be carried out in estimation level as Harrington's.1999, p.228 illustrative example prove. According to this example every customer lost for grocery store represents about $12,000 per year in lost revenue and approximately about $400 in lost profits. Harrington continues that in many organizations, quality costs caused by lost-opportunity represent more than 100 % of company's total revenue. (Harrington. 1999, p.228)

4 APPLYING COPQ

Measuring cost of poor quality is a company's key commitment to the implementation and use of quality cost system. This phase consist of quality cost identification and data collection that are discussed in this chapter (Campanella.1999, p.54). This chapter determines the difference between the prime costs of quality and overhead costs of quality and introduces a method that can be used to calculate cost of poor quality for certain actions and functions. In addition the method for determining significant cost factors among all cost factors is presented in this chapter.

4.1 Identification and data collection

An essential element in operating total-quality-control program is identification, analysis and control of quality costs (Feigenbaum.1991, p.114). Ideally cost procedure includes a complete system of costs elements that would be coded in a way that the costs of prevention, appraisal, and internal and external failures could be easily distinguished and sorted. Coding system allows all the cost to be sorted and totaled in the way that the sum of total costs for each "cost of poor quality" category can be easily determined and calculated (Campanella.1999, p.54-55; Tsai.1998, p.721).

Many different techniques such as brainstorming, nominal group technique, Pareto analysis, cause and effect analysis, fishbone diagrams and forcefield analysis can be used when determining COPQ elements (Tsai.1998, p.721). The second phase, after the quality cost elements have been identified, is to put costs in used monetary unit on these identified elements. There is criticism on quality cost literature that many researches focus on why quality cost information is important but do not concentrate on what should be included in quality costs system and how to measure and collect quality costs. The process of collecting quality data is based on searching and shifting data that have been already gathered for other purposes. However, a large portion of this information should be estimated by selected way (Tsai.1998, p.726). Juran et al.1998, p.8.13 also highlights that data need to collected by using several approaches. Following framework of data sources is presented to help the data collection:

1. Established accounts.
2. Analysis of ingredients of established accounts.
3. Basic accounting documents.
4. Estimates:
    a. Temporary records.
    b. Work sampling.
    c. Allocation of total resources.
    d. Unit cost data.
    e. Market research data.

A simple financial cost and price structure is presented (figure 18) as it helps to explore the improvements made through a quality costs study. (ASQC Quality Costs Committee.1987a, p.517)

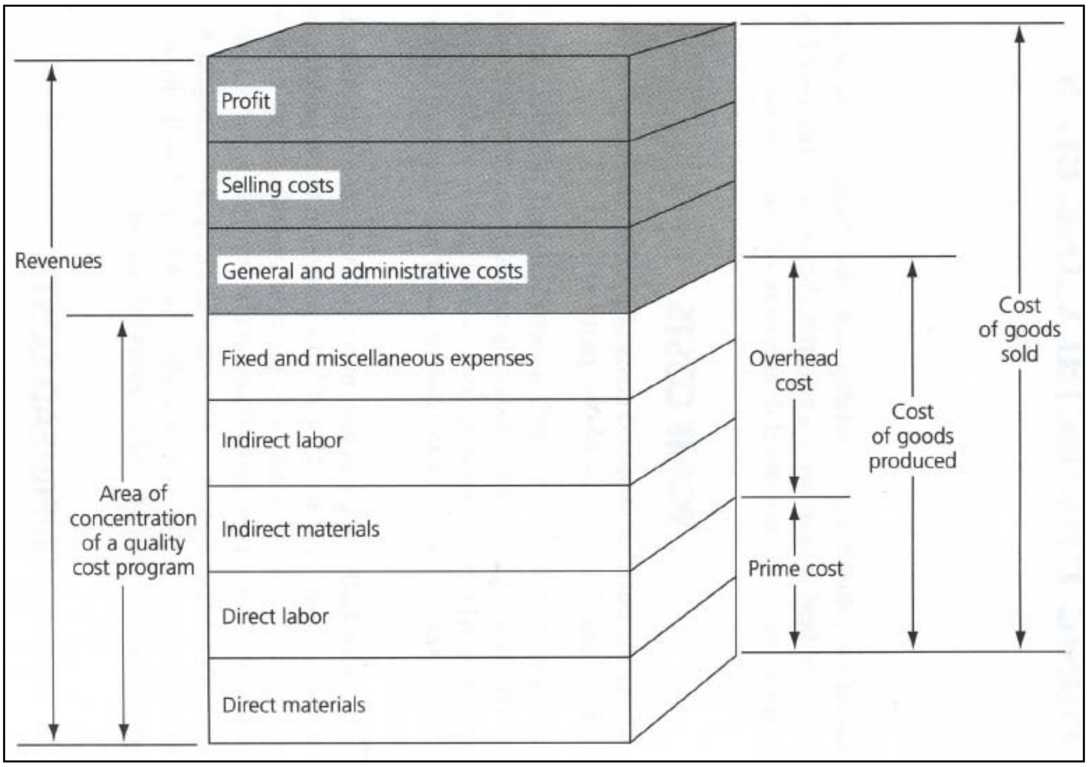


Figure 18. Traditional cost and price structure. (ASQC Quality Costs Committee.1987a, p.518; Campanella.1999, p.180)

Above figure 18 identifies, as indicated on the left side of the figure, the composition of the selling price. The size of the blocks does not imply the size of the costs. The right side of the figure identifies some terminology referred to frequently in manufacturing companies. Area of concentration of a quality cost program is the most important element in the above figure as it is a collection of quality costs. It divides all the costs of poor quality into prime costs and overhead costs. Prime costs consist of direct labor and direct material costs that can be calculated when time required to carry out processes and costs of materials needed are known. Prime costs are the basic input and necessity when producing an inventory or saleable product. Direct materials consist of raw materials, semi-finished goods and finished parts. There might be confusion between direct materials and supplies. However, supplies are determined to be used or consumed in the operation of the business but not directly in the product itself. Another element of prime costs is direct labor that is labor required to transform direct materials into finished outputs. These costs vary according the number of products manufactured. The salaries and other compensation of the workers who works directly in producing output are considered as direct labor costs. According to the above determination of prime costs it is quite certain that this category of costs can be easily identified and then calculated. (ASQC Quality Costs Committee.1987a, p.518)

Overhead costs consist in the other hand of indirect costs of materials and labor and also fixed and miscellaneous expenses that are associated with the producing output. Indirect materials consist of suppliers that are materials, which consumed in the manufacturing of the output but those are not directly used as a part of output. Indirect materials consist of suppliers such as coolants, protective boxes for material handling, shipping suppliers, perishable tools, heat, light, power to name a view of those. Indirect labor includes the salaries and other compensations of the employees that are not working directly producing the output but whose services support the production process. Therefore this particular element includes wages of foremen, process planners, truckmen and janitors to name a view. Fixed and miscellaneous expenses consist of depreciation but also taxes, rentals, and insurance costs. (ASQC Quality Costs Committee.1987a, p.518-519)

Other elements of selling price are general and administrative costs, selling costs and profit. General and administrative costs do not directly contribute to the product but are necessary for the successful conduct of business concern. These costs include costs from operations of departments such as financial, personnel, information systems and public relations. Selling costs can be determined to be the costs that are incurred in an effort to make sales and in transferring the completed output to the customer. These costs are, mainly incurred outside the factory, include warehouse costs, billing costs and transportation costs. Profit is the difference between selling price and the costs occurred. It is determined as an increase in owner's equity at the time of sale. (ASQC Quality Costs Committee.1987a, p.519)

Applicable costs of poor quality are subsequently converted to dollars by data processing. An exception is labor hours that cannot be collected on a real time basis because some of the work related to scrap cannot be divided to the costs of poor quality at the moment of making it. The work must be first be inspected, rejected, and dispositioned and only after those actions it becomes a scrap. Many companies have a procedure in which existing scrap reporting documents are sent to the estimating department which is responsible to complete an estimation of labor and material costs. However, COPQ-system should only consider the labor and material costs that are actually lost in the work accomplished up to the time of the work being scrapped. (Campanella.1999, p.55)

The problem with cost of poor quality is that these costs are rarely easily to be found from existing accounting systems as these systems were not created for this particular purpose. Rather these costs of poor quality lie buried in the standard costs and must be uncovered. Therefore there is a need to identify these costs related to poor quality and devise new accounting categories for these. This can be done by breaking down the labor costs into representing activities that are essential in terms of value-adding and to those that do not add any value. These direct costs are then separated into material or labor costs that are associated with an ideal process and costs that represent waste. After the waste is determined, data separation can be carried out using traditional accounting systems (Campanella.1999, p.61-62). However, Activity Based Costing, ABC not only makes costs separation easier but it also allows greater level of detail (Kaplan & Cooper.1998, p.3).

According to Campanella.1999, p.62-63 there are four levels at which costs are incurred as illustrated in figure 19. Unit-level costs are referred as "direct costs" because they can be assigned directly to particular units of products or services. These costs include cost of labor hour or cost of purchased materials or cost of manufacturing a unit of output. Other costs are not assignable at the unit level, since these costs depend on batch size or they fall either in category of support services or facility services. Batch-size costs depend on the size of the batch produced and these include setup time, scheduling, material handling and shipping and receiving. Batch size costs need to be spread to the units produced. Support services include costs for several products and services and contain i.e. purchasing and complaint handling. The last level of incurred costs is facility support and these expenses need to be paid no matter whether there is an output or not. (Campanella.1999, p.62-63)

Unit	Direct labor	Direct materials
	Machine hours	Energy usage
Batch	Setup	Material handling
	Scheduling	Shipping and receiving
Product support	Redesign	Engineering changes
	Bill of materials	Complaint investigation
Facility support	Property taxes	Insurance
	Depreciation	Maintenance

Figure 19. Levels at which costs are incurred. (Campanella.1999, p.62)

Costs that are not incurred on unit-level or those that cannot be assigned at the unit level are overhead costs. These costs are incurred to production support or service operations. Overhead costs consist of following three parts:

1) Indirect material costs.
2) Indirect labor costs.
3) Fixed and miscellaneous expenses.

Indirect material costs are costs of supplies consumed in operations but are not directly a part of the end product. Indirect labor usually represents the wages of employees who do not work on the end product but support the production or service process. These indirect labor costs include supervisors, operations support personnel and maintenance people. Fixed and miscellaneous expenses include depreciation, taxes, rent, warranties and insurance. (Campanella.1999, p.63)

These overhead costs in conventional accounting practice are incorporated into the standard cost in proportion to the amount of direct labor, machine hours or direct materials. In other words the amount of overhead costs assigned to the product or service output depends on the amount of direct labor is needed to produce this output. (Campanella.1999, p.63)

4.2 Pareto analysis

One of the commonly used methods for finding the most significant factors in terms among set of factors is Pareto analysis (Cervone.2009, p.76-77). This is done by prioritizing potential improvement opportunities by ranking the activities in terms of greatest opportunities for improvement (Tsai.1998, p.730-731). It is statistical decision making technique developed by ecomist Vilfredo Pareto (Cervone.2009, p.76-77). It can be used not only for prioritizing these potential improvement opportunities but also in selection of a limited number of tasks that produce the most significant overall costs of poor quality (Mohideen et al.2011, p.477).

Pareto analysis is based on 20/80-rule in which 20 % of improvement activities cause 80 % of the quality costs and therefore these are remarkable activities in terms of cost improvements. In addition 80 % off all activities produces only 20 % of problems (Tsai.1998, p.730-731; Mohideen et al.2011, p.477). Joseph Juran found out that Pareto analysis is applicable in many different areas, also in quality costs. By separating the most important factors from set of activities provides the company a possibility to focus its limited resources to the activities that have highest return on investment (Cervone.2009, p.76-77).

The Pareto chart is drawn according to the data collected and can be essential method visualizing the outcome so that management can easily find the activities in which they should be focused in order to achieve the greatest return on quality investment. Therefore it is a simple way to provide the facts needed for managerial decision making. As mentioned Pareto chart organizes all information gathered and displays it in a way that importance of various problems can be seen easily. This can be achieved by using special form of a vertical bar chart that informs the amount of costs each quality problem is causing in illustrative way. Problems are organized in order in terms of their effect so that the problems with most important opportunities for improvement are presented in the beginning (Mohideen et al.2011, p.477; Cervone.2009, p.76-77)

Pareto analysis is a creative way of looking causal effect of quality cost problems as it helps organizing thoughts. However, it needs to be noted that Pareto analysis can be limited in terms of possibility of excluding important problems that may be small at the moment but constantly growing. Pareto analysis also lack of study of relation of problems. A problem that seems to be quite insignificant can be connected to other problems that together cause a significant quality costs (Mohideen et al.2011, p.477). In addition to the clarity of the results one of the additional advantage to Pareto analysis is that it is rather easy and fast to implement (Cervone.2009, p.76-77).

4.3 Activity Based Costing, ABC

Overhead costs have increased overwhelmingly because of significant increase in automation and computer-controlled processes. Therefore there is remarkable significance how these overhead costs are assigned if there is a purpose to control and reduce them (Campanella.1999, p.65). The capabilities of financial accounting system have been criticized in terms of identifying and collecting all the costs relating to COPQ. However, one accounting method is compatible with "cost of poor quality" methodology and objectives (Campanella.1999, p.58-61).

The main functions of traditional cost accounting are inventory valuation, income determination and external reporting. Cost accounts are based by categories of expenses, instead of activities although most of costs of poor quality measurement methods are activity or process oriented. In addition conventional cost accounting allocates lot of COPQ-related costs first into overhead costs. After that these costs are guided via costs centers of different departments to products or services through predetermined overhead rates (Tsai. 1998, p.719-720). The main deprivation of conventional cost accounting is distribution of overhead costs to products or services using allocation based on bases such as direct labor hours, direct material costs and direct machine costs. However, it needs to be noted that magnitude of this distortion that is caused of this practice is based on the portion of overhead costs in relation of product costs. In other words this particular practice seems to be appropriate in environments in which the costs of non-value-adding activities and therefore the amount of overhead costs are small-scale. However, it was noted in previous chapter that in modern manufacturing environment the amount of overhead costs are constantly increasing because of the increase of automation and computerization and therefore this particular method is not longer appropriate. In addition many of overhead costs vary with volume diversity or in relation on other activities. This will lead to situation in which conventional cost account overcosts products with high volume and on the contrary undercosts products with low-volume (Tsai.1998, p.727-728). These deficiencies of conventional accounting can be overcome by using activity based costing.

4.3.1 Assigning overhead costs to products and services

ABC-techniques can be used to find and assign specific activities that create costs. Activity-Based Costing can be determined as accounting procedure that allocates the cost of indirect and overhead expenses that are the costs of an organization's resources in proportion to the use of given resource by that activity (Campanella.1999, p.58-61; Juran et al.1998, p.8.15). The aim of Activity-Based Costing (ABC) is to improve overall cost effectiveness by focusing on key cost elements. The principle of COPQ methodology is to seek to assign costs of poor quality in activities, products, processes or departments so that these costs can be targeted for reduction (Campanella.1999, p.58-61). According to Kaplan & Cooper.1998, p.3 ABC functions in the way that indirect and support expenses are first driven to activities and processes in terms of used resources and then to products, services and customers. Therefore this method gives managers a clear picture of the economics of their operations (Kaplan & Cooper.1998, p.3; Tsai.1998, p.720). Activity based costing combines cost assignment view and process view as it is illustrated in below figure 20.

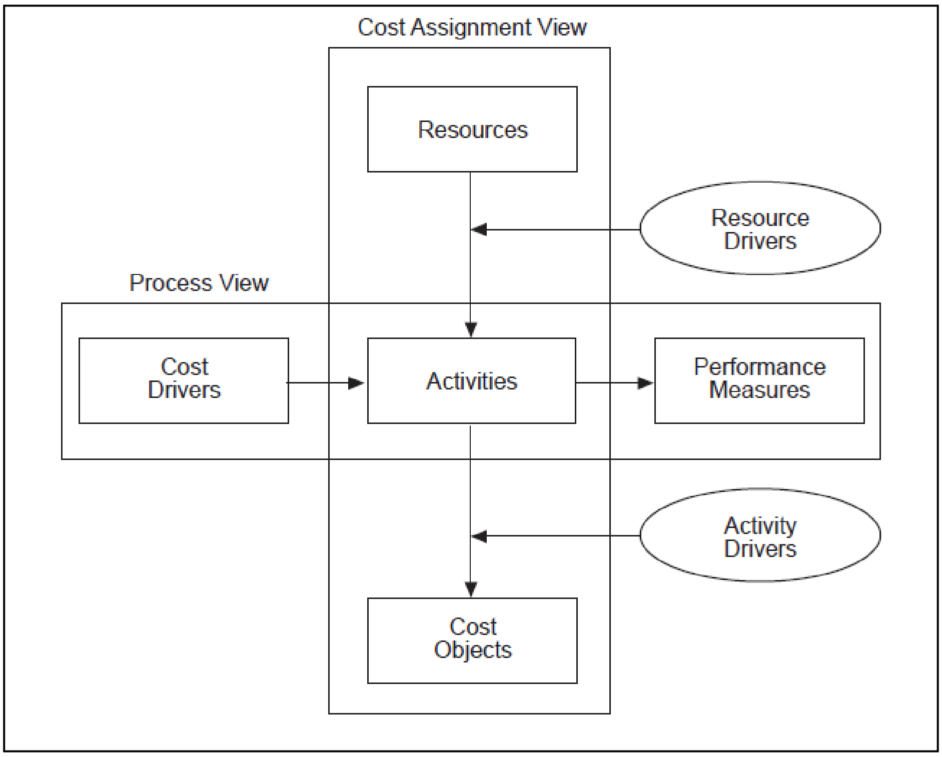


Figure 20. Two dimension of ABC. (Tsai.1998, p.728)

As it is illustrated in previous figure 20 the method for allocating resource costs to cost objects is based on two-stage procedure (Tsai.1998, p.729). In practice ABC works as an accounting method allocating overhead costs based on the factor or activities that cause overhead cost elements to be incurred (Campanella.1999, p.58-61; Juran et al.1998, p.8.15).

At the first phase allocation from resource costs to various activities is done on basis of resource drivers. Resource drivers can be determined as chosen factor that are used to approximate the consumption of resource by the activities. It needs to be noted that there can be more than one resource driver and therefore the total cost associated with an activity need to be evaluated. In the second phase of activity based costing the cost pool that is the total costs associated with an activity is allocated to cost objects using activity driver. Activity driver is determined factor that is used to evaluate the consumption of activities by cost objects. The total costs of product or service can be calculated by adding all the costs of different activities assigned to products and the unit cost of product or service can be achieved by dividing the total cost by the amount of the product or service (Tsai.1998, p.729).

Causal factors that are referred as cost drivers are measurable activities that increase overhead costs. ABC simply refines these causal factors into smaller categories that contain many cost drivers. Cost drivers are consistent method that can be used as an allocation base but instead of just one cost driver (i.e. direct labor hours) there are several cost drivers such as purchase orders, shipments, and machine setups. There may be various ways allocating overhead costs in different departments (Campanella.1999, p.58-61; Juran et al.1998, p.8.15). The level of detail and information related to quality costs received from accounting systems are often inadequate as mentioned earlier in this paragraph and therefore accounting system is insufficient in terms of continuous improvement. However, ABC-methodology is more detailed database and therefore it suits better for the needs of COPQ (Campanella.1999, p.58-61). Following figure 21 illustrates how ABC can be utilized when allocating overhead costs.

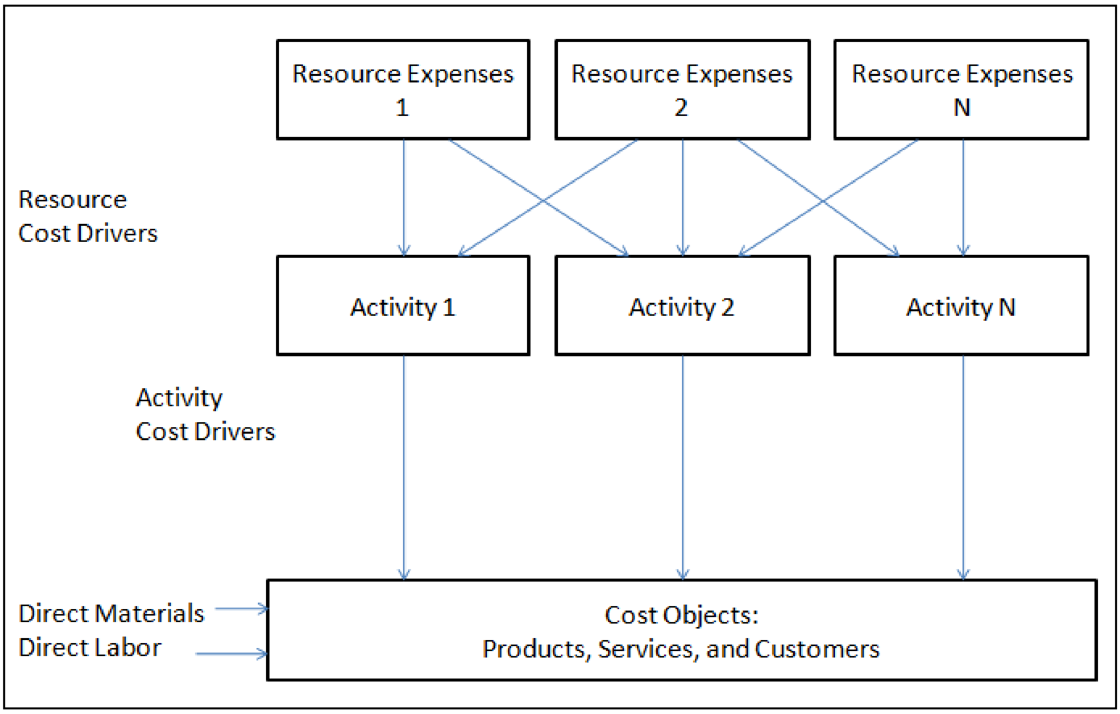


Figure 21. Activity Based Costing. (Kaplan & Cooper.1998, p.84)

As seen from above figure 21 ABC links resource expenses to the variety of products manufactured, not just volumes manufactured. However, the ABC method differs from conventional accounting as the proportion of expenses allocated to products depends on use of activities (Kaplan & Cooper.1998, p.83-84).

Overhead rate needs to be determined for each cost driver by dividing total costs for the driver by the amount of driver events. For example total costs for all complaint investigations need to be divided by the number of complaints investigated. After the overhead costs rate is determined for each cost driver, these rates can be applied. However it needs to be noted that different products, services and processes use different components of overheads. (Campanella.1999, p.63-65)

It seems that assigning overheads to products, services and processes creates a lot of work for accounting department. Actuality accounting departments would be only responsible for initial setup of the accounts that requires more accounting work – all the rest can be done automatically, accurately and cost effectively by using help of computerization. (Campanella.1999, p.65)

4.3.2 Cost-benefit analysis

The next phase after quality costs have been identified and structured is to analyze them as a basis for any appropriate action (Juran et al.1998, p.3.6). The purpose of the analysis is to measure and compare the costs associated with poor quality. This should be carried out basically for three reasons. Firstly it quantifies the size of the quality problem, it guides development and it tracks progress in improvement activities. (Juran et al.1998, p.8.1). In this particular phase each cost item is examined in relation to other items and as a whole. In addition also time-to-time comparison should be taken into account. In other words quality costs should be compared with previous results i.e. one month's operations are compared with the previous several months. Comparison is meaningful when the absolute costs of poor quality are related to the total manufacturing activity for that period. Quantity can be stated as a ratio of quality-costs or by using other comparison bases (Feigenbaum.1991, p.122, 141). When managers are using scoreboard on the cost of poor quality they do not only to look at the gross dollar figures but they are also interested in comparing the costs with measurement base. Measurement base functions as an index of the opportunity for creating these costs. According to Juran et al.1998, p.8.23-8.24 most common bases are: direct labor hour, direct labor dollar, standard manufacturing cost dollars, value-added dollars, sales dollars and product dollars (Juran et al.1998, p.8.23-8.24).

The bases selected vary upon the product and type of manufacture for a particular business. The selection of measurement bases is a significant factor in the effectiveness of the quality program. Therefore the base needs to be selected according what is most relevant for the purpose or the product (Feigenbaum.1991, p.122, 141). Juran et al.1998, p.3.6 presents two important methods, Benchmark and historical performance, that can be used when selecting appropriate bases for quality analysis. Benchmark is a concept for setting goals based on knowing what is achieved by other companies. This is a common goal that is based on requirement that processes or products need to be at least equal to processes or products offered by competing companies. Historical performance is widely used as a base for setting quality goals. In this particular method results are analyzed as a comparison to the company's past performance (Juran et al.1998, p.3.6).

Whatever the selected base the company is using the purpose of the analysis phase is to use quality costs when finding targets for improvement rather than as system of quality reporting (Juran et al.1998, p.8.1). In theory quality costs can be assigned to a root cause of quality problem. This is possible because use of quality costs is really valuable as it allows the possibility to calculate the return on investment and the payback time for investing to fix a root cause. (Campanella.1999, p.66)

D.W.Webster recommends a five-step process for using Activity-Based Costing to identify the costs of poor quality:

1) Identify all prevention and appraisal activities and internal and external failures.
2) Determine the activity costs associated with internal and external failures, and with prevention and appraisal tasks.
3) Identify activities that benefit from prevention and appraisal activities and that cause internal and external failures.
4) Assign the cost of prevention and appraisal to the activities that benefit from prevention and appraisal. Assign the costs of internal and external failures to the activities identified as the root causes of these failures.
5) Adjust calculated costs of products and services to reflect these additional costs of quality.

Czuchry et al.1999, p.362 proposes cost-benefit analysis approach to quality improvement. They advocate a system that strives to eliminate deficiencies by seeking alternative solutions to quality problems. This particular method claims that costs of poor quality have to be traced to their source or root cause, before these costs can be eliminated (Czuchry et al.1999, p.362). Root cause analysis consist of wide range of different approaches applied to reveal causes to problems. Following figure 22 illustrates that the root cause is not usually the factor that causes the problem but it is underlying deeper in the hierarchy of causes. It also shows steps that have been proven to be efficient in terms of finding root cause. (Sissonen.2008, p.35)

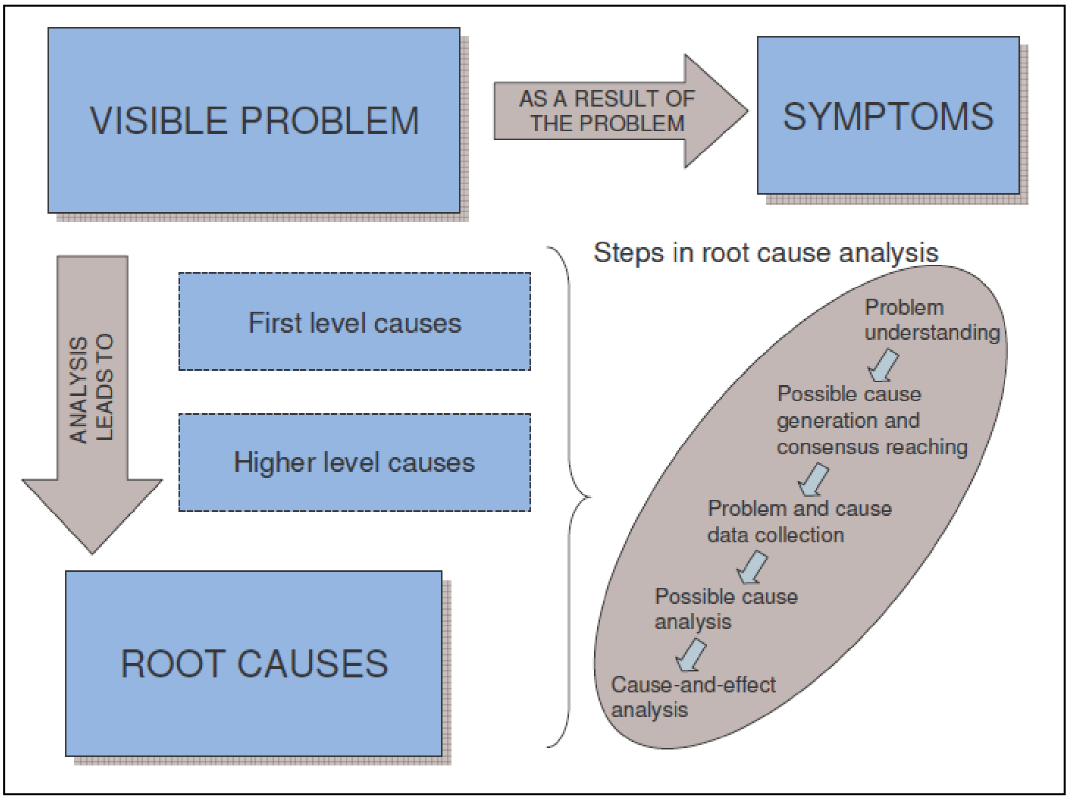


Figure 22. Root cause analysis (Sissonen.2008, p.36)

Activity-Based Costing can be used for determining the overhead costs using cost drivers but it can be also used to estimate the cost impact of fixing a cause (Campanella.1999,p.66-69). This approach is helpful for identifying a strategic direction linking quality improvements to profits through cost savings. It also provides a mechanism for determining a return on quality-related investments (Czuchry et al.1999, p.365). In the example presented by Campanella.1999, p.66-69 Activity-Based Costing has been used to determine that rework accounts for 40 % and scrap accounts for 60 % for $24,000 internal failure costs of two products shafts and housings so that Shafts are responsible for 70 % of rework and 46 % of scrap. Activity-Based Costing is then used again to determine second order drivers that are causes for scrap and rework for this particular internal failure. Figure 23 illustrates the cost breakdown structure for shafts and housings.

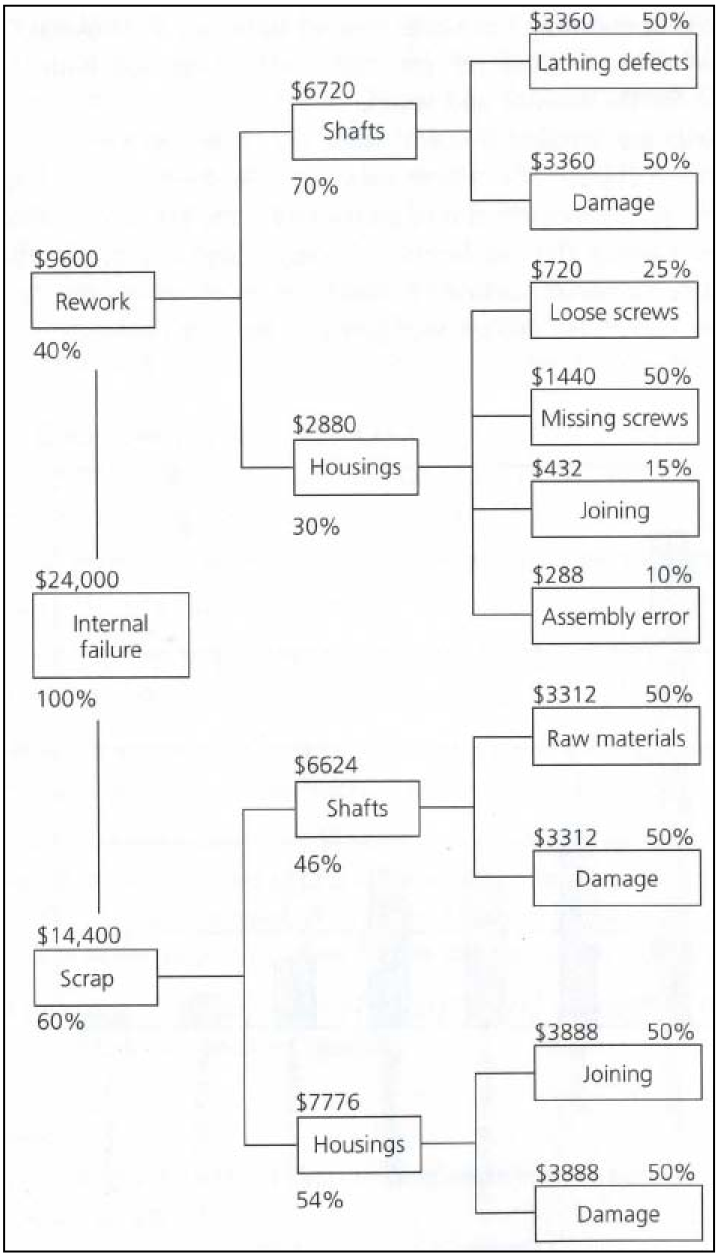


Figure 23. Internal failure costs breakdown. (Campanella.1999, p.67)

Figure 23 illustrates that rework and scrap are induced by altogether seven causes. The costs of these causes can be then summarized using Pareto-analysis to give perspective about where the biggest payback would result when the cause is corrected (figure 24). Correction of the selected cause would probably need knowledge of the root cause of the particular cause and therefore requires identification of another level of cause and cost drivers. (Campanella.1999, p.68-69)

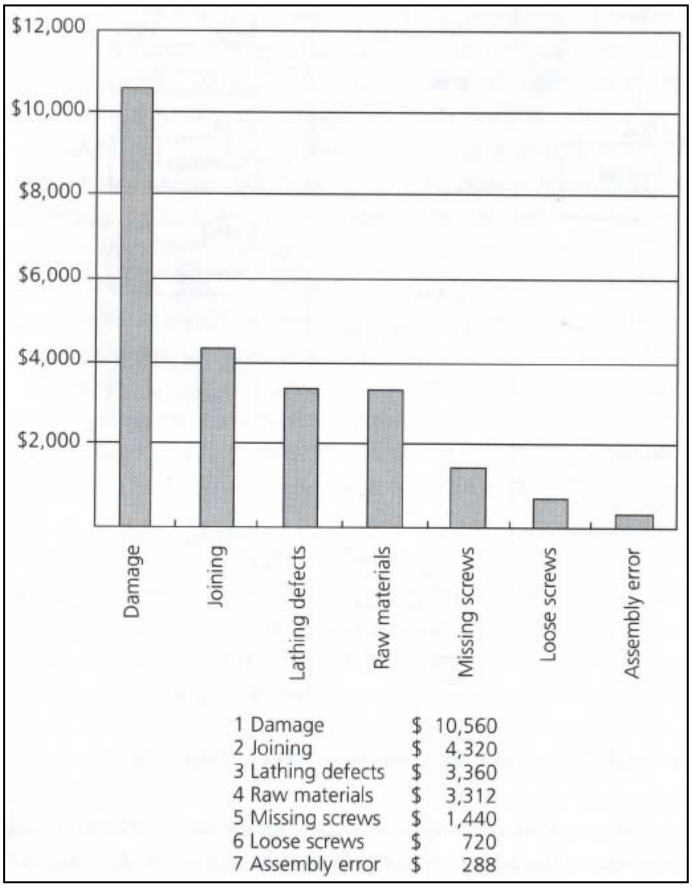


Figure 24. Causes of failure. (Campanella.1999, p.68)

In this example described above the result of "damage" is $10,560 for both materials. If a root cause that amounts for 75 % of these costs could be found, there would be a possibility to eliminate $ 7920 annually. And if it would cost approximately $4000 to fix this particular problem that relates to these damages the payback time would be about six months. (Campanella.1999, p.69)

4.4 COPQ in supply chain

Costs of poor quality in supply chain is an important theme, because in most cases company is not only buying material and services from suppliers but it is also providing its own products and services to own customers. (ASQC Quality Costs Committee.1987a, p.447). According to Crosby.1980, p.61 products and services purchased from supplier accounts more than 50 % of company's sales. This particular figure is from 1980 and between Crosby's study and the present the amount of product and services bought from external suppliers have increased strongly as the consequence of non-stopping growing competition between companies. Therefore the cost of poor supplier quality can be significant and can be a good indicator of problem areas (Campanella.1999, p.74). According to ASQC Quality Costs Committee.1987a, p.185 these vendor related costs can present a great amount of money ranging from 10 percent to 20 percent of selling price to your customer which can be considered as a great proportion.

According to ASQC Quality Costs Committee.1987a, p.285 the purpose of expending COPQ-program to study costs of poor supplier quality is to:

- Save in operating costs quality assurance.
- Assure better quality and vendor performance.
- Reduce reject rates.
- Build confidence in the end product.
- Reduce in-house and field costs.
- Increase customer satisfaction.

The materials and services coming from supplier and entering the company on a continual basis make a dedication to defect prevention and acceptance necessities. Therefore Crosby highlights the purpose of product and service control (Crosby.1980, p.61-62). According to Campanella.1999, p.74 the system of managing and tracking costs of poor supplier quality is similar with the one that is used to identify internal costs of poor quality. Direct costs of poor supplier quality are apparent and can be quite easily to be identified and assigned to various suppliers. These costs of poor supplier quality consist of prevention, appraisal, internal failures and external failures (Campanella.1999, p.74). Accurate description of direct supplier costs according to ASQC Quality Costs Committee.1987a, p.186 is as follows:

Prevention includes:

- Quality control administration.
- Quality system planning and measurement.

- Vendor Quality surveys.
- Quality data analysis and feedback.

Appraisal includes:

- All inspection and test costs.
- Laboratory acceptance testing costs.
- Vendor quality audits and surveillance.

Internal Failure includes:

- Rework.
- Scrap.
- Retest and inspection.

External Failure includes:

- Returned material processing and handling.
- Warranty replacement.

However, according to ASQC Quality Costs Committee.1987a, p.447 key understanding in supplier quality costs is to recognize that much of these costs are hidden. Hidden costs are not really easily identified or perhaps not even seen as vendor related quality costs. These hidden costs of poor supplier quality are usually viewed from customer’s point of view. (ASQC Quality Costs Committee.1987a, p.447). As studying these costs from customer point of view Campanella.1999, p.74 divides these hidden costs of poor supplier quality into three parts:

- Costs incurred by supplier at the supplier’s facility.
- Costs incurred by the buyer in solving problems at the supplier’s facility.
- Costs that are not usually allocated to suppliers but incurred by the buyer as a result of potential or actual supplier problems.

Costs incurred by supplier at the supplier’s facility are the same types of quality costs that also incurs at buyers facility. However, these costs are included in the unit or service price that the customer is paying. Therefore it might be possible that supplier is trying to protect the identification of this investment for competitive reasons. As a result a buyer in the supply chain can only view these costs as part of the unit price and can conclude the competitiveness and the amount of waste only by comparing this price with the offers of other potential suppliers. (ASQC Quality Costs Committee. 1987a, p.447).

According to above examination the costs incurred by supplier at supplier facility are unknown to buyer and therefore hidden. These costs include all the costs from prevention and appraisal actions taken by the supplier in order to firstly to avoid poor quality from occurring and secondly in inspections that are done before outputs are released to customer (Campanella.1999, p.75). Even if supplier is a small shop there need to be done preventative and appraisal actions so that the output would meet the criteria set by customer (ASQC Quality Costs Committee.1987a, p.187). In addition to these controllable costs of poor quality, deviation is expected to occur and therefore supplier has also failure costs as unfortunately we all make errors despite the size of the company (Campanella.1999, p.75; ASQC Quality Costs Committee.1987a, p.187.) These defected materials need to be scrapped or reworked which cause internal failure costs. In case that this deviation in output's quality is not found at supplier facility and it is delivered to customer in the results that customer is not satisfied, external failure costs occur. These defected products or services that are already delivered to customer need to either redo or replaced with the new output. These supplier quality costs that incur at their facility incurs no matter the size of the supplier. (Campanella.1999, p.75)

Costs of poor supplier quality that are incurred by the buyer in solving problems at supplier's facility are not usually specifically allocated to suppliers (Campanella.1999, p.75). These costs are spent to insure that the quality of supplier's product or service meets the customer's requirements (ASQC Quality Costs Committee. 1987a, p.447) Therefore these costs are hidden. However, these costs of the effort and travel expenses have sometimes tabulated in order to give awareness to troublesome suppliers. These costs include i.e. costs of sending a quality engineer to a supplier to resolve a crisis. (Campanella.1999, p.75)

Hidden quality costs incurred by the buyer as a result of solving potential or actual supplier problems are that which the customer spends in-house in order to ensure that supplier products or services actually meets the requirements. These costs are also rarely segregated (ASQC Quality Costs Committee.1987a, p.447.) According to Campanella.1999, p.75 these costs may include the following:

- Specifying and designing actions and measurements needed to take and use by buyer’s receiving inspection and in some case also by supplier in inspection prior the shipping.
- Designing specifications to be used by supplier in the manufacture or when performing the service.
- Adding special quality control effort that is specifically related to supplier product, in the buyer’s production line.
- Determining the acceptability of supplier’s material by reviewing test and inspection data.
- Loosing production time due to unavailability of appropriate material.
- Internal and field engineering required to analyze and correct a problem caused by supplier.

These costs of poor quality of suppliers participating within supply chain have a cumulative effect on the Original Equipment Manufacturers (OEM) COPQ. This cumulative effect of cost of poor supplier quality in total COPQ of supply chain is illustrated in figure 25. (MetricStream.2011)

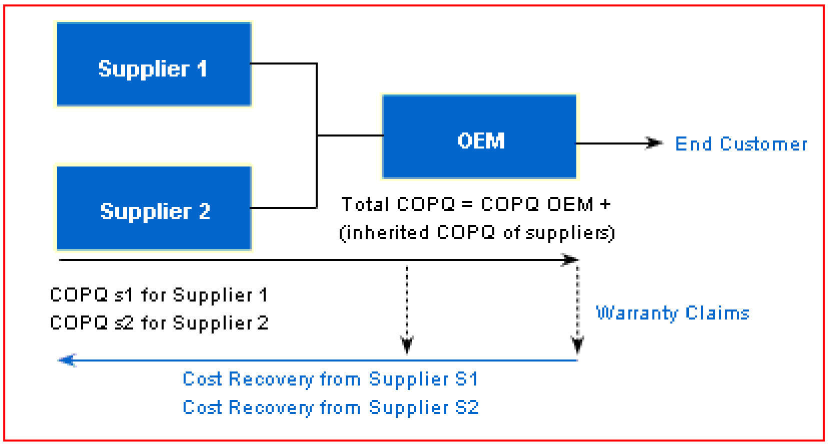


Figure 25. Total COPQ in supply chain. (MetricStream.2011)

According to the above figure, OEMs inherit costs of poor quality of their suppliers. Therefore companies are working very proactively with their suppliers to reduce their COPQ. Many OEMs have also implemented supplier cost recoveries, which are also called as supplier charge-backs, in order to charge costs of non-conforming components and materials and late deliveries from suppliers. When considering supplier related costs of poor quality these are the costs that relates to external failures. Therefore these failures do not only create direct costs but can also compromise the future performance of supplier. The costs of poor supplier component quality are associated with the costs incurred in complaint handling and in connection with claims against warrant. A warranty is a contract between customer and supplier. It specifies that supplier is agreed to credit, repair or replace the defected product within predetermined warranty period. There are two different warranty types presented in literature that are failure-free warranty and pro-rata warranty. The difference between these two types of warranties is that the supplier is charged to the total cost of repairing within the warranty period in failure free warranty. However, in pro-rata warranty supplier is only responsible for specified portion of repairing costs. The proportion of supplier cost depends on proportional age of the failed output (Miguel & Pontel.2004, p.312-313). This system is an effective way to introduce business discipline to quality and accountability into supply chain. Cost recovery system can be therefore used effectively to force suppliers identify the root cause of quality problem and to implement corrective actions. (MetricStream.2011)

Two other methods of controlling both the hidden and visible costs of poor supplier quality are emphasized. The first method includes talking vendors into adopting COPQ-program. The second using quality cost program to identify high magnitude vendor problems for resolution. Quality costs can be significant ingredient of vendor relationship as vendor relationship depends upon more than the traditional measures including meeting deliveries and receiving inspection rejections. Supplier relationships must recognize the "fitness-of-use" of the supplier's products and services for which visible quality costs can be a valuable indicator. (ASQC Quality Costs Committee.1987a, p.186)

4.5 Application to COPQ to Supplier Control

OEMs are interested in reducing costs of supplier quality because ultimately buyers are responsible for the waste of supply chain. An application to COPQ to supplier control begins with the determination of what supplier-related quality costs are important. The first step is therefore to use company's cost of poor quality program to compare the costs of poor quality by category and by element. Pareto analysis can be then used to find out which suppliers are mainly responsible for causing the main problem determined in previous step. Usually the results of Pareto-analysis suggests that only relatively few suppliers are causing the most of the problems. After the determination of the problem and suppliers that cause this problem can company focus on these selected issues and suppliers and take appropriate actions to reduce costs related to problems. (Campanella.1999, p.76; ASQC Quality Costs Committee.1987a, p.189)

Visible costs of poor supplier quality can be used in many ways. Some companies demand credit notes and therefore debit vendors for the scrap and rework occurring in the buyer's plant. This method puts the responsibility where it hurts most – in the pocketbook. However, this method has been criticized as in the long run this could be counterproductive in the way in which vendors are just increasing the price of their products to cover this situation. Another way to use the information from COPQ-program in order to reduce the business given to the offender and rewarding the good performer by allocating greater share of purchase orders to them. A far more positive method to use the information from COPQ-program is to jointly improve supplier problems. (ASQC Quality Costs Committee.1987a, p.189)

There is no all-inclusive appropriate action that could be used in all situations in which suppliers are causing significant amount of costs in terms of poor supplier quality but supplier needs to find and solve root causes for each problem that exists. However, convincing the vital few suppliers to institute quality costs programs seems to be practical as the program supports supplier to take actions in cost reduction in fields that causes most of the costs of poor quality. In other words quality cost programs aims to reduce costs in areas that are most visible to the buyer and therefore the quality of the supplier's product/service and buyer's product/service will improve. Quality improvements will decreases costs and therefore there are either more profit to be shared by supplier and buyer or possibility to increase the competiveness of the supply chain by lowering prices. In addition to quality cost program launched by supplier, buyer may have supplier rating system in place that can be used to monitor supplier's quality costs. (Campanella.1999, p.76-77; ASQC Quality Costs Committee.1987a, p.189)

5 MAJOR FINDINGS FROM LITERATURE RESEARCH

According to Philip Crosby quality is not only free but it can be a profit maker. Every dollar that is not spent on doing things wrong becomes a dollar right on the bottom line. (Crosby.1979. p.2). Quality Cost System is one of the tools that aim operational savings in terms of improving quality and reducing related costs. In order to capture opportunities for cost savings by improving quality it is crucial to understand the characteristics of quality cost system and to implement it company's operations in a way that these opportunities for improvements can be found without excessive use of company's limited resources.

There are many determinations of quality and some of those are even excluding each other. In the widest determination quality has two aspects that are quality of design and quality of conformance. However, the quality cost literature concentrates mainly defining quality as "conformance to requirements" as it allows quality to be managed. Management in previous sentence indicates that quality should be measured as it reflects the overall state of the company and this particular measurement should be carried out using monetary units. According to Feigenbaum.1991, p.114 the quality cost system for total quality control involves three stages:

1) The identification of quality-cost items.
2) Quality-cost reporting that includes related analysis and control.
3) The ongoing maintenance of the program to ensure that business objectives of higher quality at lower costs are met.

The goal of any COPQ-system is to enhance quality improvement efforts that will lead to operating cost reduction opportunities in following five ways:

1. Quality information presented in currency helps management to relate to the problem and therefore it is easier to get management's attention.

It translates quality out of abstract and makes it a reality that can effectively complete with cost and schedule.

2. COPQ-system helps to change the way employees think about errors: understanding the cost of errors they make will have greater impact on employees' future performance when compared to situation in which all the defected materials are only scrapped.
3. COPQ can be used to identify opportunities and to help to prioritize those opportunities and to set target and measure progress. Therefore it provides a better return on the problem solving efforts as the corrective action can be directed at the solutions that will bring maximum return.
4. It provides a mean to measure the true impact of corrective actions.
5. COPQ provides a simple, easily to understandable method of measuring what effect poor quality has on the organization.

In the third chapter of this paper the overview of quality costing models were presented. Most of quality books and other academic research used in this paper concentrate on P-A-F-model that divides operating quality costs into four categories: prevention costs, appraisal costs, internal error costs, external error costs. This particular model seems to be appropriate for measuring quality costs as it gives managers an immediate overview on which level the significant problem lies. In simplicity it advices managers to increase quality cost activities and improvements mainly in prevention as the rule of the thumb suggests that in-house prevention is about 100 times cheaper than external errors. However, the large proportion of quality costs should be invested in appraisal activities as those can lead to finding of root causes of the problem. It seems that quality cost literature has a strong focus on determining different quality cost models but there is not that much information how these models function in reality. Measuring quality costs using this particular model have limits as there are altogether hundreds of different quality costs factors that should be examined using P-A-F distribution. However, conventional quality cost calculation is based on many different information sources and in many cases most of those costs are not actual but only estimated by company's management. In addition overhead costs are divided mainly in terms of product volume and not in terms of actual resources used. In summary the methodology of continuous improvement in terms of focusing on prevention and appraisal activities should be applied by any company that seeks to improve their operations by decreasing the costs associated with cost of poor quality. However, this particular quality cost model seems to be appropriate for companies that have quite simple operations and in which the management have a consensus that the relatively accurate cost of poor quality information will lead to improvements in quality.

Another model presented in the same chapter is statistical model that uses quality loss functions that is designed not only to capture the direct but also hidden costs of poor quality that were hard to capture using P-A-F-model. This can be achieved by using robust design of quality loss mathematical function. As a mathematic model Quality Loss Function has also disadvantages in terms that cost coefficient variable is in most cases estimated. Estimations are usually based only on what quality engineers believe that variable should be. Therefore, the failure determining appropriate value for variable will lead to situation in which the whole calculation is biased. Also the QLF uses symmetrical distribution of quality loss but in most cases the actual distribution of quality loss is asymmetrical. Despite the disadvantages of QLF it seems to be appropriate when quality costs need to be measured by comparing the realized quality character value with the target quality character value. However, when this model is applied, extensive focus need to be given in determining appropriate variable values.

Activity Based Costing methodology is an accounting procedure that allocates overhead costs in proportion of the use of given resource by activity. ABC functions in the way that indirect and support expenses are first driven to activities and processes in terms of used resources and then to products, services and customers as it is illustrated in figure 21. ABC differs from conventional accounting as the proportion of expenses allocated to products depends on the use of activities. Therefore the use of ABC methodology will distribute quality costs accurately and managers will have a clear picture of economics of their operations.

Literature review indicates that P-A-F model together with ABC methodology provides a mean for quality cost calculations. These models give an answer what should be measured and how this measurement should be carried out. However, when product or service quality costs are incurred when quality character derivates from target value, then QLF seems to be most appropriate methodology for quality cost calculation. These methodologies were applied when creating a quality cost calculation method for supplier performance ratings.

Researchers are debating on issue of optimum quality level. The traditional model of quality costs suggest that the optimum level would lie somewhere below 100 % quality level as the costs of prevention and appraisal activities would increase exponentially when approaching 100 % quality level. However, the new model of quality costs suggest that total costs of quality have its minimum at the 100 % quality level as investments in prevention and appraisal activities allows those to be carried out more cost effectively and the loss of sales could be significant under 100 % percent. Literature review did not reveal which of those quality cost models would be most appropriate. Findings of this paper however highlight the importance of cost-benefit analysis that can be used to evaluate the costs and benefits of fixing particular quality problem. Pareto and root cause analysis seems to be appropriate when evaluating the opportunities for improvement and weighting costs of improvements versus the estimated savings from these improvements.

Poor quality costs at supplier level can be categorized and measured mainly similarly as those at OEM level. Hidden costs of poor supplier quality can be divided into three levels:

- Costs incurred by supplier at the supplier’s facility.
- Costs incurred by the buyer in solving problems at the supplier’s facility.

- Costs that are not usually allocated to suppliers but incurred by the buyer as a result of potential or actual supplier problems.

Findings reveals that the poor quality costs of other equipment manufacturer includes also poor quality costs of suppliers as those are included in component or service prices. Literature research reveals that these costs are transferred to the sequential level of supply chain if those are not requested to be credited using warranty claims which seem to be appropriate when improving overall quality of supply chain.

6 COPQ – CASE COMPANY MODEL

6.1 Company presentation

Case company employs about 130 000 employees in about 100 countries. It is publicly owned company and is quoted on stock markets in Sweden, in Switzerland and in New York. Company's headquarters is located in Zurich, Switzerland. Revenue from year 2010 was 32 billion USD. (Harri Heimonen, 2011)

Case company is one of the world's leading engineering companies that offer its customers products, systems and services that help customers to use electrical power efficiently, increase industrial productivity and to lower environmental impact in a sustainable way. Case company's product portfolio covers:

- Electricals, automation, controls and instrumentation for power generation and industrial processes.
- Power transmission.
- Distribution solutions.
- Low-Voltage products.
- Motors and drivers.
- Intelligent building systems.
- Robots and robot systems.
- Services to improve customers productivity and reliability.

Main clients are industrial and energy companies. Current strategy is based on rise in electrical consumption by 2035 under current policies. Following figure 26 illustrates how consumption of energy is estimated by World Energy Outlook 2010 to grow from 2008 to 2035 and what are case company's solutions are to respond to the demand (Harri Heimonen, 2011).

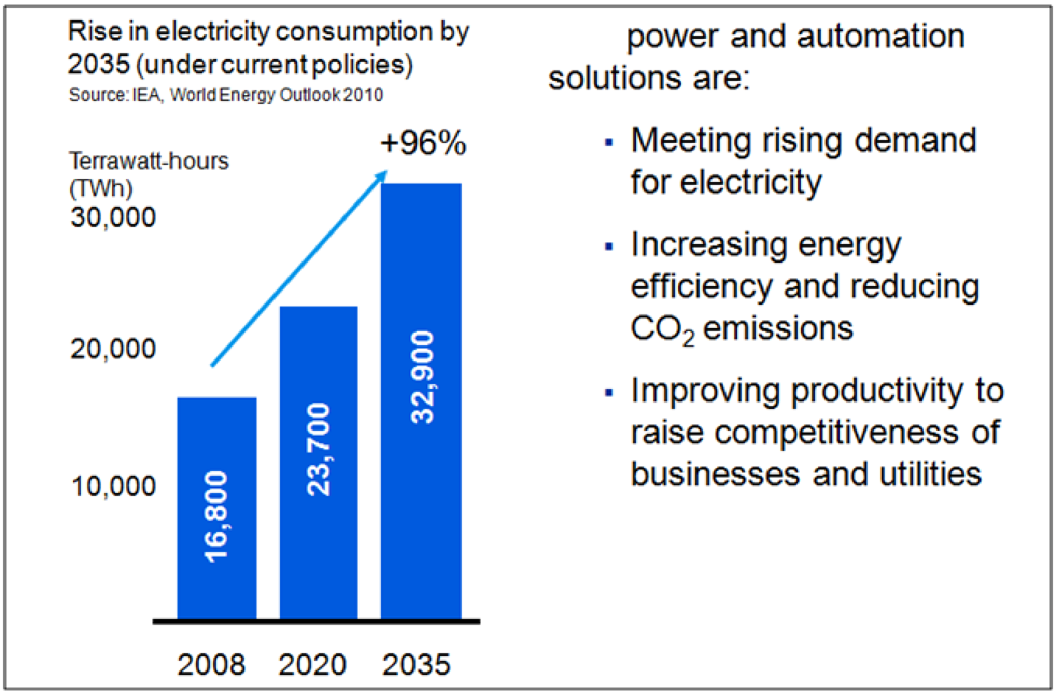


Figure 26. Rise in electricity consumption and case company's solutions (Harri Heimonen, 2011).

Case company consist of group of companies that are divided into five different divisions followingly: Power Products, Power Systems, Discrete Automation and Motion, Low Voltage Products and Process Automation (Harri Heimonen, 2011). Following figure 27 presents revenue and amount of employees per division in year 2010.

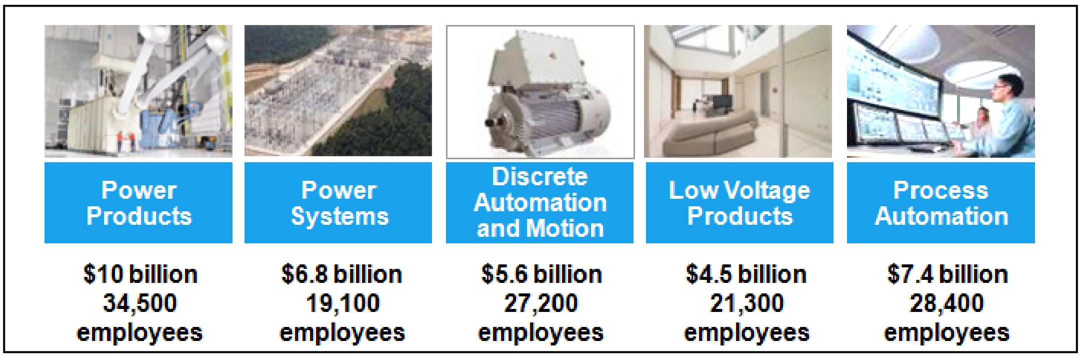


Figure 27. Divisions. (Harri Heimonen, 2011)

Following figure 28 presents how orders were divided per business field and region in 2010. In addition also the share of employees in emerging markets (EM) and mature markets (MM) is presented in same figure. The purpose of this figure is to present that case company has local foot print all over the world and the current strategy supports this ideology.

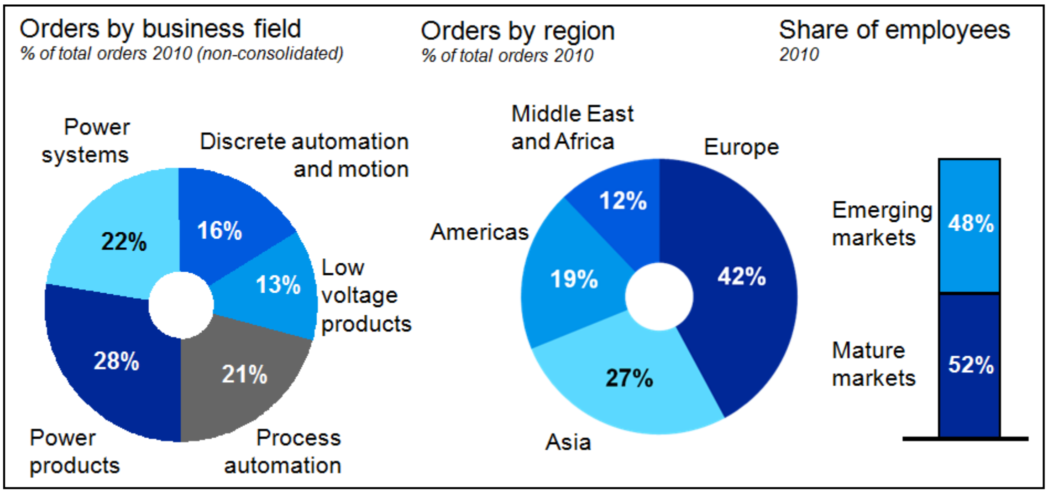


Figure 28. Share of orders per business field and region in 2010. (Harri Heimonen, 2011)

6.2 Total Quality Management at case company

Cost of poor quality is determined in case company as “the sum of costs resulting from products or services not conforming to requirements or customer/user needs”. In general cost of poor quality includes all those costs that would not have been incurred if the quality of case company’s products and services were perfect. Case company’s new quality strategy defines COPQ as cost opportunities by perfecting quality. (Harri Heimonen, 2011)

Case company has similar kind of cost of poor quality classification as P-A-F model. The main difference between those models is that poor quality cost categories are referred with terms “cost of conformance” and “cost of non-conformance”. “Cost of conformance” refers to “cost of control” category in P-A-F model and hence it includes the expenses of prevention and appraisal activities that are aimed to ensure that case company’s products and services meet expectations. “Cost of non-conformance” refers to “cost of failure of control” in P-A-F model and therefore these costs are occurred when expectations are not met. These costs can be internal if costs are occurred prior to delivery or service or external if costs are occurred after the delivery. Following figure 29 highlights the case company’s cost of poor quality categories and points clearly connection to the P-A-F model. (Harri Heimonen, 2011)

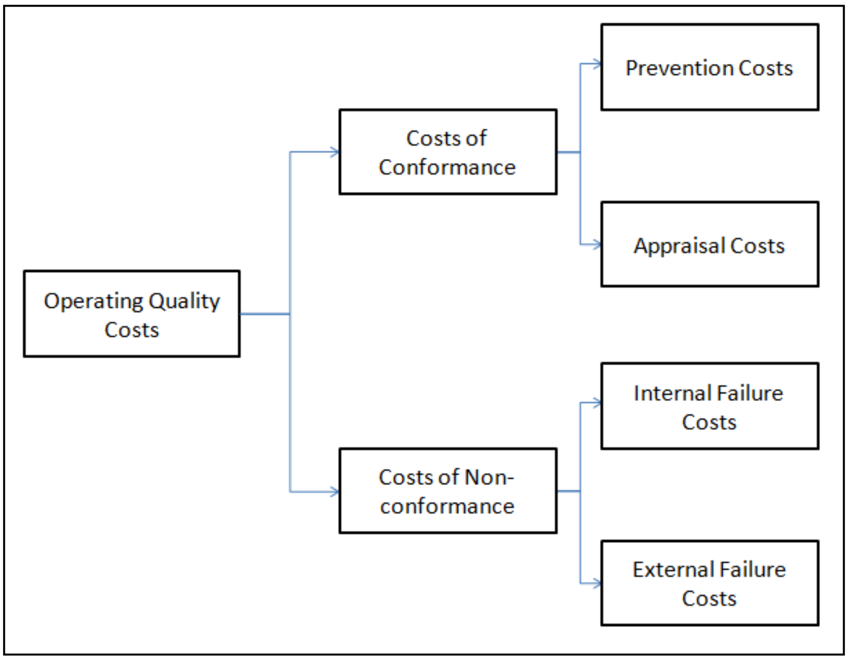


Figure 29. Case company’s Cost of Poor Quality model (Harri Heimonen, 2011)

In addition to general classification of cost of poor quality costs case company organizes quality costs by business processes. A more detailed listing of the COPQ categories is presented in Appendix 3. (Harri Heimonen, 2011)

The main purpose for cost of poor quality in case company is to identify opportunities for improvement. The main principle is to first collect COPQ date until it provides level of genuine transparency. The second phase is to observe the trends and identify elimination opportunities. OPEX and 4Q methodology for problem solving are one of the main tools that are used when cost of poor quality is eliminated in case company. Next these two tools are determined briefly. (Harri Heimonen, 2011)

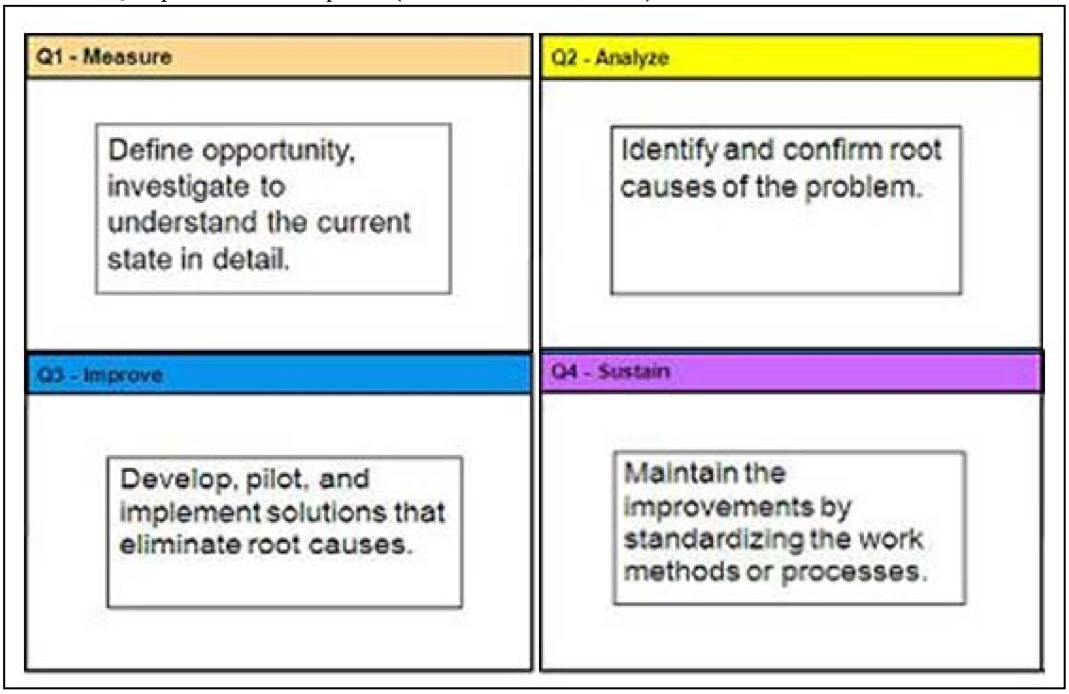
OPEX

The purpose of OPEX is to stimulate and support the achievement of operational excellence across case company. It provides a common framework for continuous improvement within case company. OPEX contains the structure, training, tools and methods to harness the problem solving ability of everyone across company. It focuses on projects that improve customer satisfaction, business result, and safety. OPEX aims to secure continual delivery of cost savings year over year. OPEX is built upon case company's widely accepted 4Q methodology for problem solving. (Harri Heimonen, 2011)

4Q method for problem solving

As case company business has become global in nature it is helpful to have a common approach to making improvements. Using the same method, tools, and terminology will allow employees to work together more efficiently to resolve issues both inside and outside case company. The name "4Q" refers to the four quadrants of the reporting template that are measure, analyze, improve and control. Improvement teams step through each quadrant using simple quality can make significant improvements efficiently in company's business. The 4Q Method has been used in engineering, production, project management, offices, workshops, and countless other locations inside of case company. It has also been used with Suppliers to improve their On Time Delivery and Quality of Delivery. Following table 4 illustrates the main purpose in each quadrant. (Harri Heimonen, 2011)

Table 4. 4Q Improvement Template. (Harri Heimonen, 2011)



6.3 Supplier Performance Rating at case company

Most of the suppliers that delivers components or semi-finished products to case company are been monitored using supplier performance rating which is carried out quarterly. Supplier performance rating is carried out by commodity sourcing manager together with inbound logistics coordinators and product support inside case company. However, the seasonal meetings with supplier are followed within short period of time. The purpose of this sub-chapter is to give a clear picture about the content of supplier performance rating and how different factors are measured.

As the current supplier performance rating is mainly based on quality factors such as product quality and availability. These two items presents main proportion supplier performance rating. This main proportion of score in supplier performance rating is divided as follows. Supplier is given up to halve of it from availability that includes scores from On-Time-Delivery (OTD) and scores from their buffering performance. Another halve of the main proportion of scores is quality based and it is given to suppliers according the amount of complaints made in proportion of amount of all materials delivered. Therefore the measurement unit for quality is defected Parts per Million (PPM). In some product groups such as in power semiconductors quality performance include evaluation of field performance.

All the factors of supplier performance rating mentioned above are measured automatically using company's Enterprise Resource Planning (ERP) system. Complaints need to be executed manually but the system keeps track of all complaints that can be searched from the system with the many different search conditions but the most logical in terms of supplier performance ratings is to search the complaints per selected supplier per selected quarter of year. When the amount of complained components and the amount of delivered components are fed to supplier performance rating excel-sheet it will automatically calculate the PPM rate for selected supplier.

ERP system automatically measures OTD by comparing the wished delivery date with the actual delivery date for every purchase order line. Purchase order lines are then categorized into four different groups that are:

- early.
- OK.
- late.
- very late.

In supplier performance rating case company determines all purchase order lines that are either early or OK to be delivered on-time and "late" and "very late" are deviations but the matter of how late the purchase line is delivered is not handled. Therefore On-Time-Delivery can be easily be measured by calculating the amount of on-time purchase order lines in proportion of all purchase order lines. This is also done by feeding the information searched from the ERP system to the supplier performance rating excel-sheet.

Also Buffering performance is automatically measured using ERP-system. Case company has visibility to suppliers buffering levels as they have granted limited access to the information of their own ERP-systems. Supplier is then given responsibility to either automatically or manually to update their buffering levels weekly. Information of supplier's buffering levels can be search from case company's ERP-system so that the average buffering levels for selected period of time is attained.

The rest of supplier rating is based on supplier co-operation and development. This particular factor differs from previous ones as it cannot similarly referred as "hard measurement indicator" as it is based on evaluation carried out by commodity sourcing manager, inbound logistics coordinators and technical support.

However although the current supplier performance rating formula gives basis for this thesis, this study is not limited only to study these aspects of supplier's quality that are already known but the objective is to study alternative reasons that create costs in terms of poor quality.

7 COPQ MEASURE SCHEME FOR SUPPLIER PERFORMANCE RATING

The focus of the case study is to determine the way to evaluate the costs of poor quality for availability and component quality. The third category of supplier performance rating namely co-operation and development is already excluded from this study as those were measured based on the objective evaluation and not on based on performance measurement. The result of this chapter is separate models for component quality and availability that can be applied for quality cost calculations. This particular chapter is divided according to the field of studies into following subcategories: component quality and availability.

7.1 Component Quality

Component quality is measured in case company supplier performance rating tool by calculating the proportion of complained items in relation of all items delivered to case company. Rating points are not given in linear fashion but in accelerating way as a result of using different formulas. However, the rating points are given in that particular way the cost of poor quality for poor component quality is evaluated in this study in a linear fashion. In this paper the costs of poor quality are based on the number of complained components. Following table 5 illustrates monthly complained pieces and its percentage proportion of supplier components from January 2011 to December 2011.

Table 5. Perceived Quality.

	Complained pieces	Delivered Qty	Delivery Quality %
Jan - 11	1316	1 223 222	99,90
Feb - 11	920	1 095 181	99,92
Mar - 11	1526	1 399 755	99,89
Apr - 11	592	1 476 206	99,96
May - 11	829	1 652 386	99,95
Jun - 11	2379	1 314 696	99,82
Jul - 11	2862	1 423 500	99,80
Aug - 11	2490	1 436 020	99,83
Sep - 11	1778	1 225 701	99,86
Oct - 11	2979	1 175 961	99,75
Nov - 11	1982	1 264 735	99,84
Dec - 11	1394	1 164 484	99,88

Above table 5 illustrates that although the delivered quantity can fluctuate within the examined year the delivered quality percentage has remained close to 100 %. The amount of complained pieces has been though fluctuating from about 600 pieces up to almost 3000 pieces. The average amount of complained pieces in 2011 which is 1754 will be used in this master's thesis in situations in which anything is measured in proportion of supplier complaints.

Two different methodologies that are P-A-F-model and ABC are used together in order to calculate cost of poor quality for supplier component quality. Sequential use of these two different costs of poor quality methods allows first to determine the cost factors related to poor component quality and then to relatively accurately to investigate resources required performing those activities. Field interviews including brainstorming were used in order to find and select cost factors that were then divided according to P-A-F model. After cost factors are determined Activity Based Costing model is applied in order to reveal resources used. It is applied in this master's thesis in a way that the traditional cost and prices structure suggests. Costs of those resources are based mainly in internal bookkeeping and actual costs caused in similar occasions. This particular research method was chosen as it seems to be most appropriate as it does not only consist of main direct costs of poor quality presented in P-A-F model but it seems to also capture non-value-adding activities in a logical way. Therefore field study is conducted in order to capture required activities related in poor component quality. The field study had following stages:

1) Identification of component groups.
2) Checklist of cost elements involved in these component groups.
3) Cost data collection.
4) Verification of costs involved in component poor quality costs.
5) Reporting achieved results.

In the other words the first purpose of this field study is to identify the sources and contributing factors of cost of poor quality per activity. The sum of all of these factors presents the overall cost of quality that can be used in supplier performance rating. This particular process will be carried out by focusing on labor and material costs and miscellaneous costs of these activities.

7.1.1 Description of cost elements

Cost factors of poor component quality were gathered using interviews and brainstorming with steering group of this thesis and related departments within case company. Field interviews were mainly conducted to material logistics team and in-bound logistics team within selected department within case company. Following figure 30 illustrates cost factors found and organized according P-A-F model.

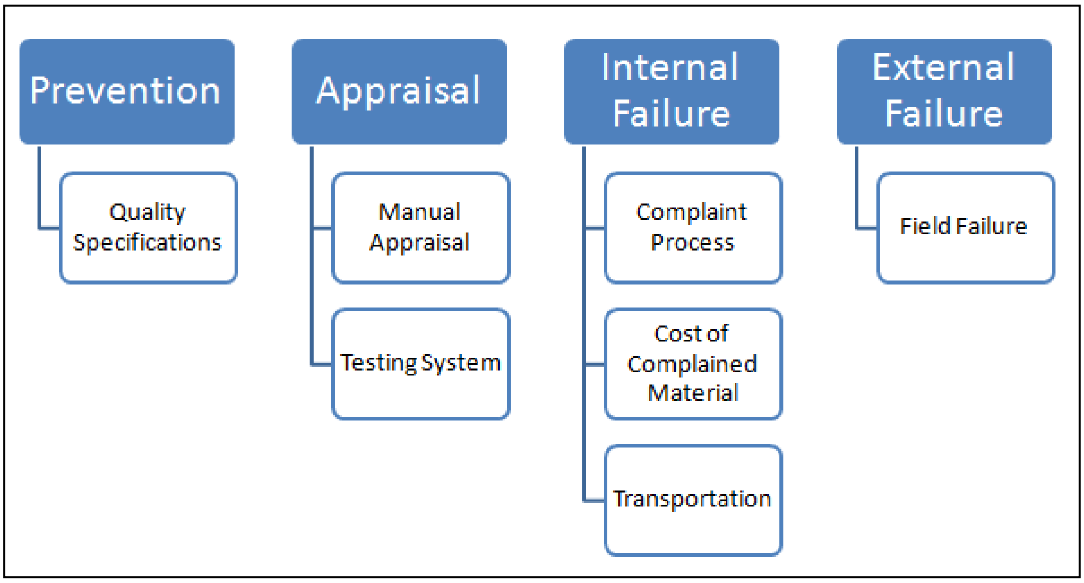


Figure 30. P-A-F model of component quality cost factors.

In order to gather valid information for those cost factors related to poor component quality more interviews were organized. These interviews included product engineering team, laboratory functions and forwarding functions among others. These categories of P-A-F model are investigated more carefully using ABC methodology and other appropriate models in order to obtain true costs or at least as accurate information as possible about cost factors.

According to the first interviews about supplier component quality mechanical and electrical components are handled differently within case company. Further examination provided more support that those have dissimilar poor quality costs. Hence, examination of costs elements of component quality will be implemented separately for mechanical complaints and for electrical complaints. Nevertheless, the structure of this sub-chapter will be carried out in a way that P-A-F model suggests.

7.1.2 Prevention

Actions that are aimed to prevent poor supplier component quality include determining strict material based quality specifications to supplier and testing the material before taking it in use. Determining component quality specifications take place when new components are designed. As this action is mainly carried out once per product life cycle it was decided not to take part in cost of poor supplier component quality calculations. In addition to determining quality specifications to components conformance of those requirements need to be tested at case company's laboratory. It is tested whether component meets given specifications and how external loading factors affect on components functionality. Testing is carried out before component is accepted and in cases that component needs to be amended or in case of many quality issues. The amount of testing needed is not depended on the amount of defected components found at production. Hence, it was also decided that the cost of testing is excluded from cost of component quality calculations. Excluding prevention from the examination supports case company's point of view about cost of quality as their own cost of poor quality methodology suggest that prevention should not be part of any poor quality calculations.

7.1.3 Appraisal

There is not a separate process for inspecting quality of incoming materials. Therefore possible deviation in component quality is found either on assembly line or at electrical testing of semi-finished or finished goods. It needs to be noted that electrical testing is designed to spot any deviation from functionality of electrical components in an end-product. Hence, the costs of electrical testing system will be suitable only for electrical complaints.

Manual Appraisal

Defected material will be placed to complaint shelf in case of one separate quality deviation but if there are many similar defects found in assembly line will material logistics team be informed about quality deviation. Complaint shelf have four different areas for different purposes: materials that come from production that are believed to be defected, the materials that need to be tested in laboratory, materials that need to be complained to supplier and materials that are tested in laboratory that need to returned to production. Dividing complaint shelf to these four distinct categories help to lead the whole complaint process in case of separate quality deviation as components are located to areas according to the need of following task needed to be carried out.

In case of more severe quality deviation in terms of amount of possible defected materials are not that straightforward as there is always a risk that there are not enough appropriate components for production. Therefore required resources are given right away to these possible defected materials in order to separate those that are defected and those that can be used in production. If possible defect is found at electrical testing, will the amount of work be significant as in many cases these semi-finished or finished goods need to be transferred from testing machine as those need to be first disassembled in order to remove possible defected components and then re-assembled and re-tested. Figure 31 presents how costs of manual appraisal per complaint are calculated using ABC-methodology.

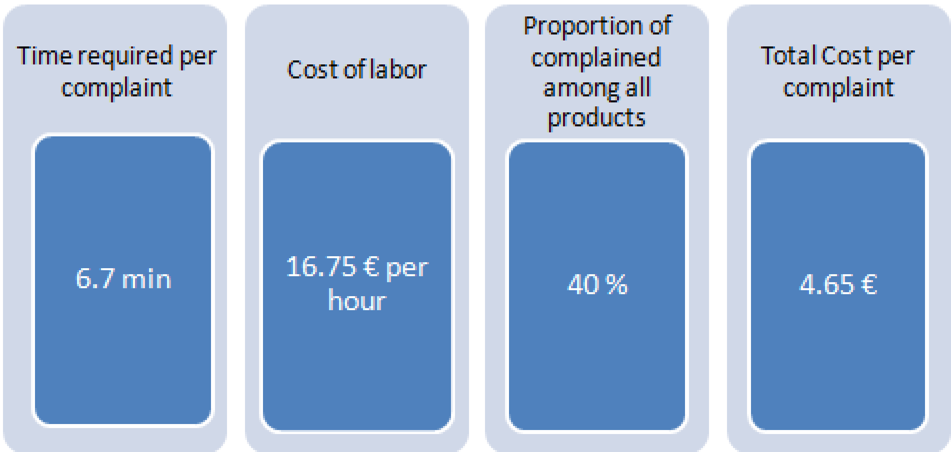


Figure 31. Cost of manual appraisal per complaint.

The process of appraisal is estimated to take about 6.7 minutes per complaint and as it is carried out by employees at assembly line the hourly labor cost is 16.75 €. Hence, cost of appraisal per complaint is 1.87 €. This amount consist only appraisal of those products that are actually defected. In addition there are also products that are detected but those turn out to be according the specifications. The proportion of defected products among all products that are detected is estimated to be approximately 40 %. Thereby the overall cost of appraisal function per complaint is 4.65 €.

Electrical testing system

Some proportion of defected materials are found in appraisal occurred in testing system and therefore additional work is needed to correct the problem or changing the defected material to the material that is working as per specifics. Electrical testing system is designed to spot any deviation from end-product in terms of electrical functionality. Hence, these costs are only related to electrical complaints. In addition it needs to be noted that functionality of mechanical products are mainly based on their dimensions and therefore the probable deviation in mechanical products functionality is seen before electrical testing system in a way that framework of the end-product cannot be assembled.

As the amount of testing done internally is constantly increasing the amount of defects found at testing is similarly constantly growing. In order to capture the costs associated with the component defects found at testing the field interview took place. It was decided to study more carefully one production line and the results from the study will be generalized to refer all the production lines within case company. Following figure 32 illustrates how costs of appraisal at testing system per complaint are calculated. These costs are described exactly within this sub-chapter.

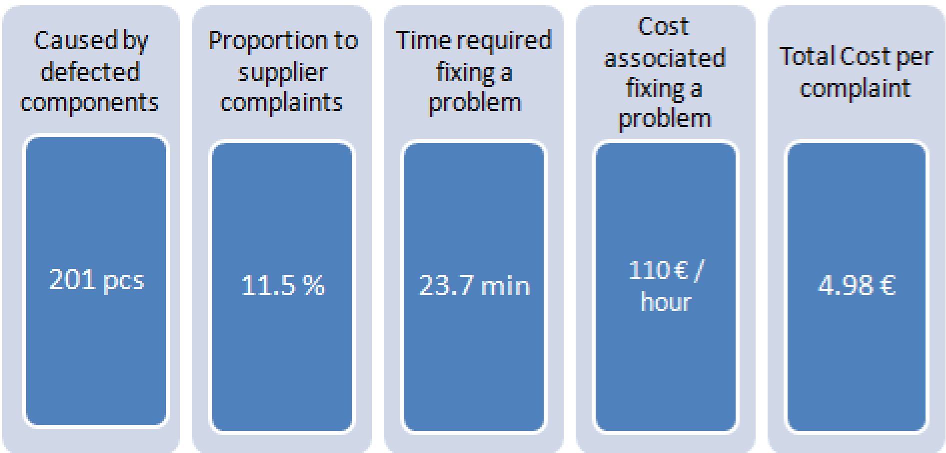


Figure 32. Cost of appraisal at testing system per complaint.

Information of testing system from selected production line was gathered from year 2011 in order to determine the proportion of manual appraisal and appraisal done at testing system. This observation indicates that the weekly percentage of approved end-products at final testing system has been variating from 97.3 % down to 88.2 %. The average of approved end-products in 2011 is 94.2 %. Data gathered from observation indicates that the trend of approved end-products has a slightly decreasing trend. The average percentage of approved end-products at testing system were averagely around 94 % in the beginning of the year 2011 and around 93 % in the end of the year 2011. Hence, this indicates that the amount of appraisal carried out at final testing will increase in the future. This information is in line with case company's actions to improve and increase the final testing in order to decrease the amount of defected end-products delivered to customers. The average percentage of approved end-products that is 94.2 % is going to be applied in cost of poor component quality calculations. In addition the information gathered indicated that 3.3 % of all end-products tested have been rejected because assembly has been carried out imperfectly. Those are found well at final testing. The rest presenting 2.5 % of all end-products being tested is derived from defected components.

According to the selected production line supervisor average amount of tested end-products is 310 pieces weekly. Hence 2.5 % that have defected components represents 7.75 pieces on weekly basis on selected production line. In addition to selected production line selected department have two other production lines that have testing system with similar costs. Hence, selected department have 3 times testing costs of investigated production line. In addition, it needs to be noted that investigated departments represents about halve of the sales of case company it can be estimated that the testing costs of whole entity is equivalent of 6 times of testing costs of selected production line. Thereby 46.5 pieces are estimated to be investigated more carefully at testing system in case company. As the average amount of weeks per month is 4.33 the amount of end-products to be detected at testing system is about 201 pieces on monthly level as illustrated in first pillar of figure 32. The total amount of complaint per month has been approximately 1754 pieces monthly the frequency of appraisal at testing system is about 11.5 %.

Time required to fix the problem depends directly on the problem that needs to be fixed and it can change from 10 seconds up to three working hours. The production manager at selected production line estimated that the average time required to fix the problem is 23.7 minutes. This particular time requires not only white collar labor but it also eats proportion of testing system's capacity. Hence the hourly cost that includes is 110 €. As the time required to fix the problem is averagely 23.7 minutes, hourly cost 110 € and frequency in proportion of supplier complaints is 11.5 % the cost associated with appraisal at final testing costs 4.98 € per complaint.

7.1.4 Internal Failure

Complaint process can be used to calculate the direct costs caused by complaints found in case company. Therefore the complaint process includes the study of all activities required to investigate and return defected material back to suppliers. In addition to returning defected materials there is a need to purchase more material from supplier. Therefore the costs of purchasing and transporting these compulsory materials are included as internal failure costs of cost of poor component quality. Interviews indicated that mechanical and electrical products are handled differently within complaint process because the detection of underlying problem requires different methods. Therefore it is appropriate to study these two cases separately. Figure 33 presents current process used to process complaints and resources needed to perform those. Theses phases of complaint process are investigated further in order to obtain more information about resources in terms of labor time and materials needed to perform those.

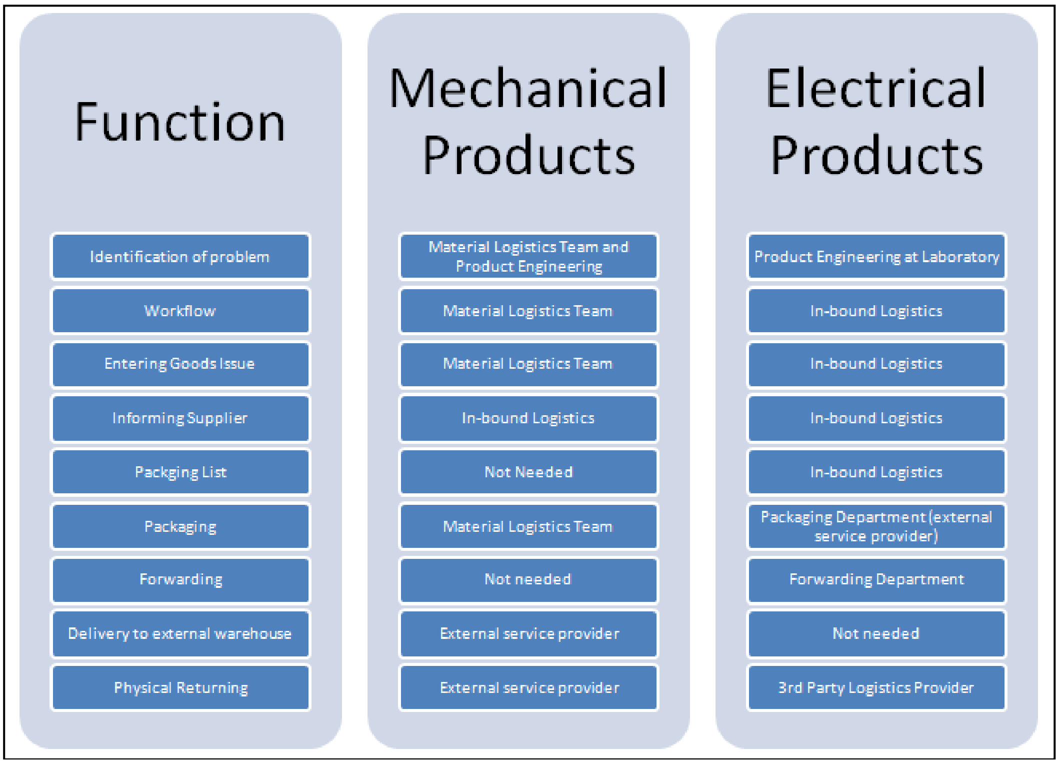


Figure 33. Current complaint process within case company and resources needed.

Identification of problem

The process of identification of problem is different for mechanical and electrical complaints and thereby both cases are discussed separately. Cost related identification of problem per complaint is calculated for both cases using ABC-methodology (figure 34). These costs are described more carefully later on.

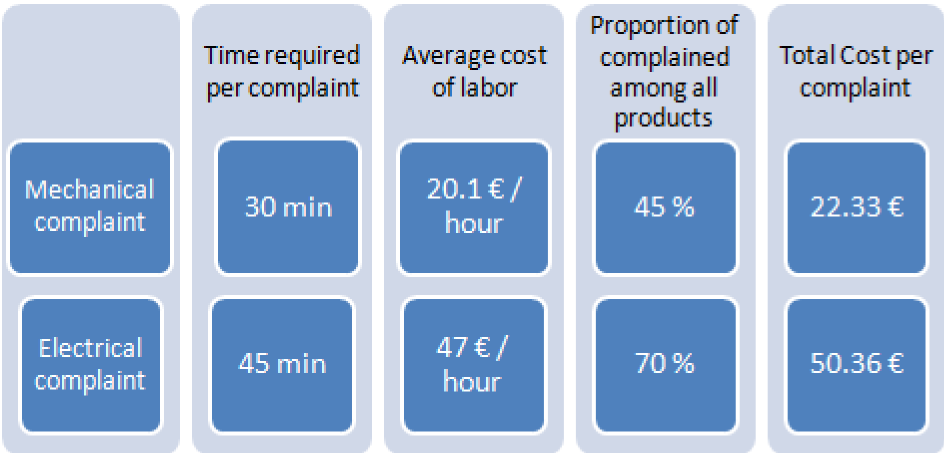


Figure 34. Cost of identifying the problem per complaint for mechanical and electrical complaints.

Mechanical components are first investigated visually and potential problem features are compared with the features of non-defected components. This particular process is carried out by material logistics team. If visual inspection will not provide a clear definition whether or not component is defected the responsibility of investigation process will be continued together with support of product engineering. The help from product engineering is needed as end-products are designed in a way that external features of mechanical components have strict upper and lower level limits. Exceeding these limits would jeopardize the reconcilement of the mechanical components in assembly process into end-product be not possible. In addition these deviations would affect the functionality of end-product. Therefore the responsibility of product engineering is compare features of components with determinate specifications. It was revealed that product engineer is working closely together at least with one member of material logistics team.

Approximately the task requires 15 minutes of blue collar employee costing approximately 16.75 € per hour and 15 minutes of white collar employee costing about 23.45 € per hour. The cost to carry out inspection for mechanical products costs altogether 10.05 € per complaint. This cost is valid only for those mechanical products that are found to be defected. In addition identification of problem is carried out for mechanical products that are not found to be defected. The proportion of defected mechanical products among all mechanical products where the problem is identified is approximately 45 %. Hence the costs of identifying the mechanical problem per complaint are 22.33 €.

Visual inspection and product support are appropriate problem investigation methods in case that underlying component defect may lie on external features of component. Therefore these methods are only appropriate to investigate external problems. Deviations in electrical product’s functionality need to be verified in laboratory. Employees of product engineering that are working in laboratory fetch components that are suspected to be defected from four complaint shelves daily.

Within these items are components that are defected in case company's processes and those that were already defected when those arrived in case company.

The purpose of laboratory process is to find the root cause of the component electrically testing it using tools such as oscilloscope, multimeter and different testing systems. Most common faults are defected component in item, couplings and base of printed circuit board but also temperature, load, tension and other external factors might have an effect on how item is functioning. According to the field interview it is more probable to find the root cause for item that is not functioning at all when comparing in situation in which the item is working but the testing system shows that there is underlying defect. When these underlying defects are found, those are more rarely complained to suppliers as it is believed that suppliers cannot verify the defect. Special consideration is also given before returning those items back to production as it is possible that these underlying defects might have an effect on functionality of end-product during its life-cycle. Therefore some proportion of tested items is needed to be scrapped.

The purpose of the laboratory function is to find standard problems in electrical items so that large amount of items with most common problems can be stopped from assembled to end-products and delivered to customers. Ideology in laboratory process is that only those items that can be clearly evidence to be caused because of supplier will be complained to supplier. The process of finding root cause includes removing of components from items. Therefore supplier could not repeat the same testing that took place at case company and therefore these items that need process of removing some components in order to find the underlying root cause of the problem cannot be complained to supplier. However this process provides case company more information about different quality problems and this information can be used in case that same defect is found in the future allowing the whole detection of root cause to be carried out faster and also allowing items to be complained to supplier. As it is seen from previous description, the product engineering staff at laboratory gives pressure to suppliers only when it is considered to be necessary because complaining items that are not clearly suppliers fault would affect on credibility.

According to the interview the time needed to find the root cause of problem changes case-by-case and it can take from 0.5 hours up to whole working day. Because of the expertise of the product engineering staff at laboratory it takes approximately 45 minutes to detect the product and find the root cause. It needs to be noted that in addition to labor hours needed to inspect electrical component also laboratory hours are needed. Hence, the cost including the labor and laboratory capacity is 47 € per hour that will be also the cost of inspection for electrical products. In addition the interview indicates that in order to sustain credibility case company cannot return all defected electrical products to suppliers. The estimated proportion of electrical products that are complained to supplier is 70 %. Hence the cost of identifying problem per complaint is 50.36 €.

Workflow process

Workflow process contains all the steps needed to record the complaint in the ERP system used by case company. This is quite straightforward process including entering valid information such as supplier information, product and amount information, reasons for complaint and demands. Workflow process is illustrated in following figure 35.

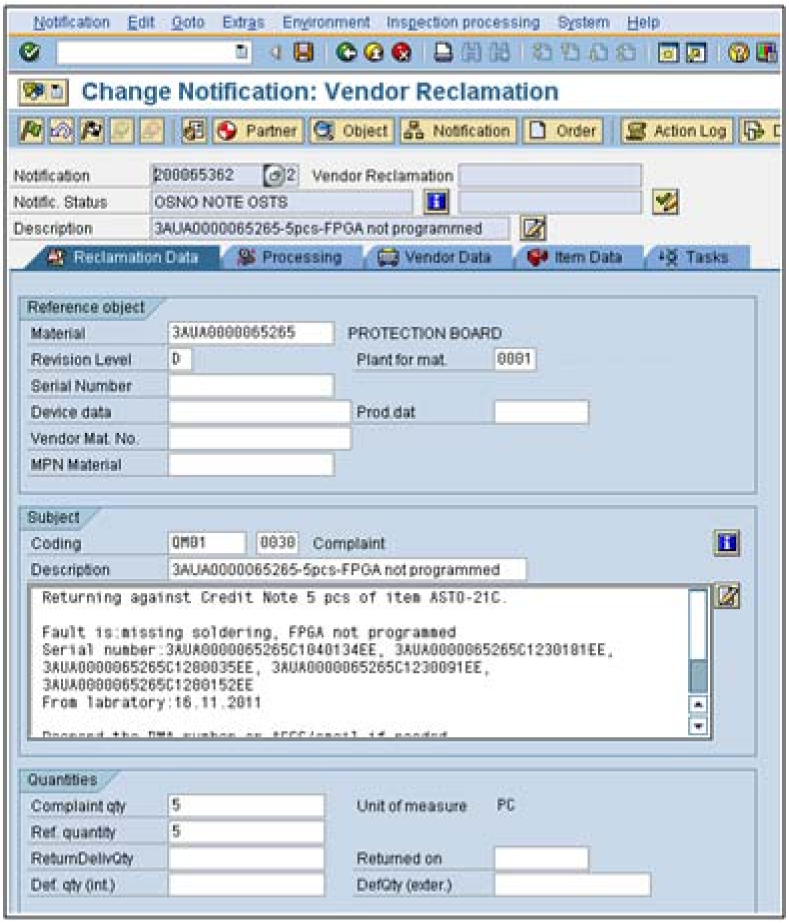


Figure 35. Vendor Reclamation.

ERP System automatically creates notification number for complaint that is used as reference number for complaint. Complaint information is also automatically transmitted to ASCC which is Internet based portal for supplier co-operation. Suppliers can see all the details of complaint when logging in to ASCC with their username and password. This particular channel is also used when supplier respond to the complaint. Costs of workflow process are illustrated in below figure 36.

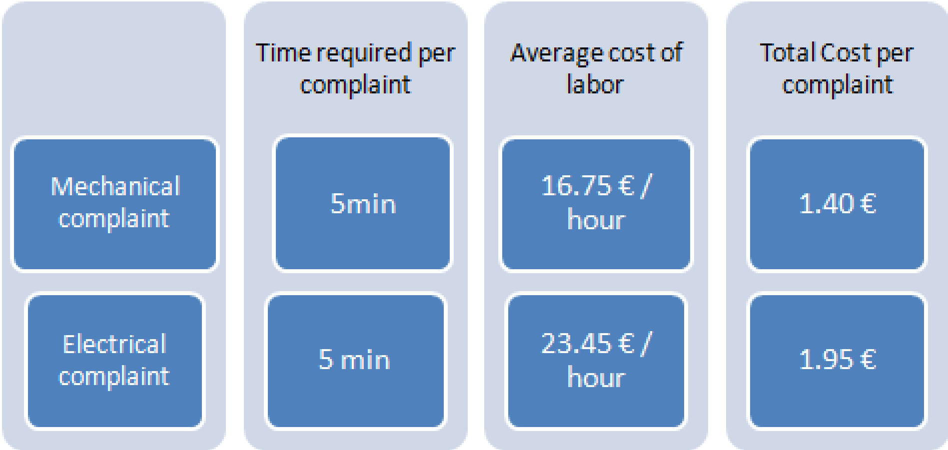


Figure 36. Costs of workflow process for mechanical and electrical complaint.

This is estimated to take up to 5 minutes. In mechanical complaint this phase of complaint process is carried out by material logistics team having hourly cost of 16.75 € and in electrical complaint process this is performed by in-bound logistics team costing 23.45 € hourly. Thereby the cost of workflow process for mechanical products is 1.40 € and for electrical products 1.95 €.

Entering Goods Issue

In addition to workflow process components are taken out of case company's account. This is also very straightforward process that is done in ERP System. Entering goods information contains of two different phases. All the valid information needed in the first phase is notification number that was created in previous phase, movement type which is in this case 551 and the account where these components are taken away. This first phase and second phase of entering of goods issue are illustrated in following figure 37.

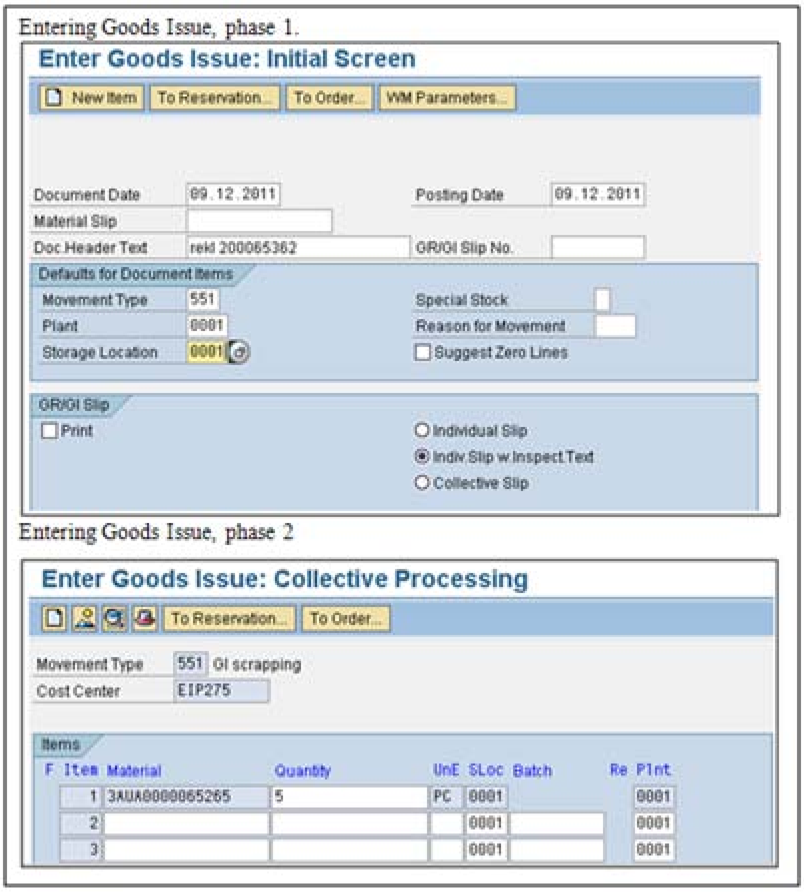


Figure 37. Entering Goods Issue

The second phase of entering goods issue includes entering the cost center of material, material code and amount of defected materials. Material code and amount of defected materials are already known but cost center for material can be found under material code and it requires little bit of additional work. Illustrative figure of second phase of entering goods issue is seen below. The costs of entering goods issue for electrical and mechanical complaint are illustrated in below figure 38.

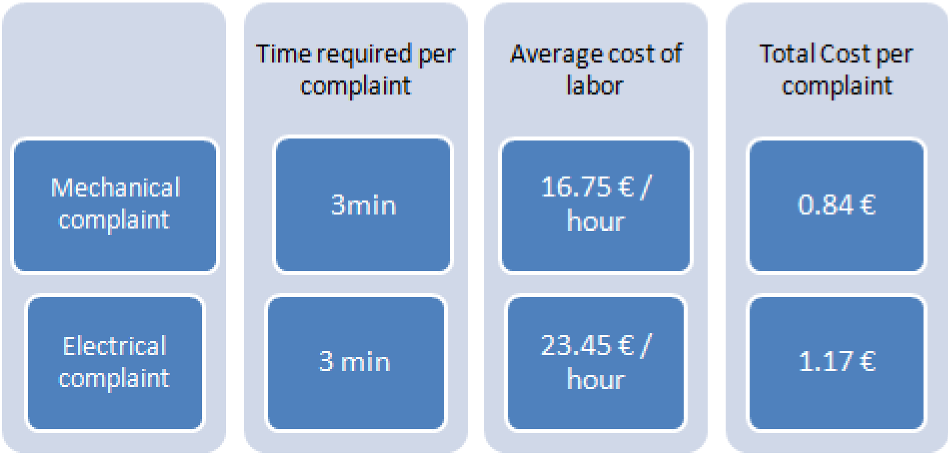


Figure 38. Cost of entering goods issue for mechanical and electrical complaint.

According to estimations both phases requires together approximately 3 minutes as seen from above figure. Entering goods issue is also carried out by different group of employees for mechanical products and electrical products and therefore those have different labor costs. Hence, the cost for mechanical products is 0.84 € and for electrical products 1.17 €.

Informing supplier

In-bound logistics is responsible for informing supplier about upcoming complaint. This phase of complaint process includes a short description about found defect and what material and how many pieces are affected. This can be done by attaching a complaint note or excel sheet including all valid information about complaints. However, many purchasers might also give a supplier a call in case in which substitutive components are needed as soon as possible. In some cases especially when supplier is located overseas the complaint process requires also supplier reference number that is also then asked in the e-mail. The costs associated with informing supplier are presented in figure 39.

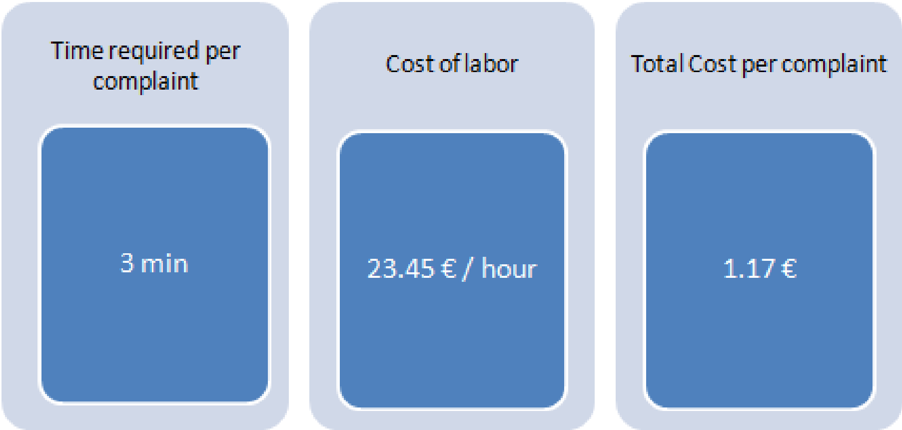


Figure 39. Costs of informing supplier.

Cost of informing supplier has been calculated using ABC-methodology as in every cost calculation so far. The task of informing supplier is estimated to take about 3 minutes and it is carried out by in-bound logistics coordinators. The cost of informing supplier per complaint is thereby 1.17 € as illustrated in above figure.

Packing List and Proforma Invoice

Packing list and proforma invoice are tasks that need to be done in case defected material is going to be returned to the country where customs clearance is needed. Following figure 40 highlights what information needs to be entered to packing list and proforma invoice base that exist in excel form.

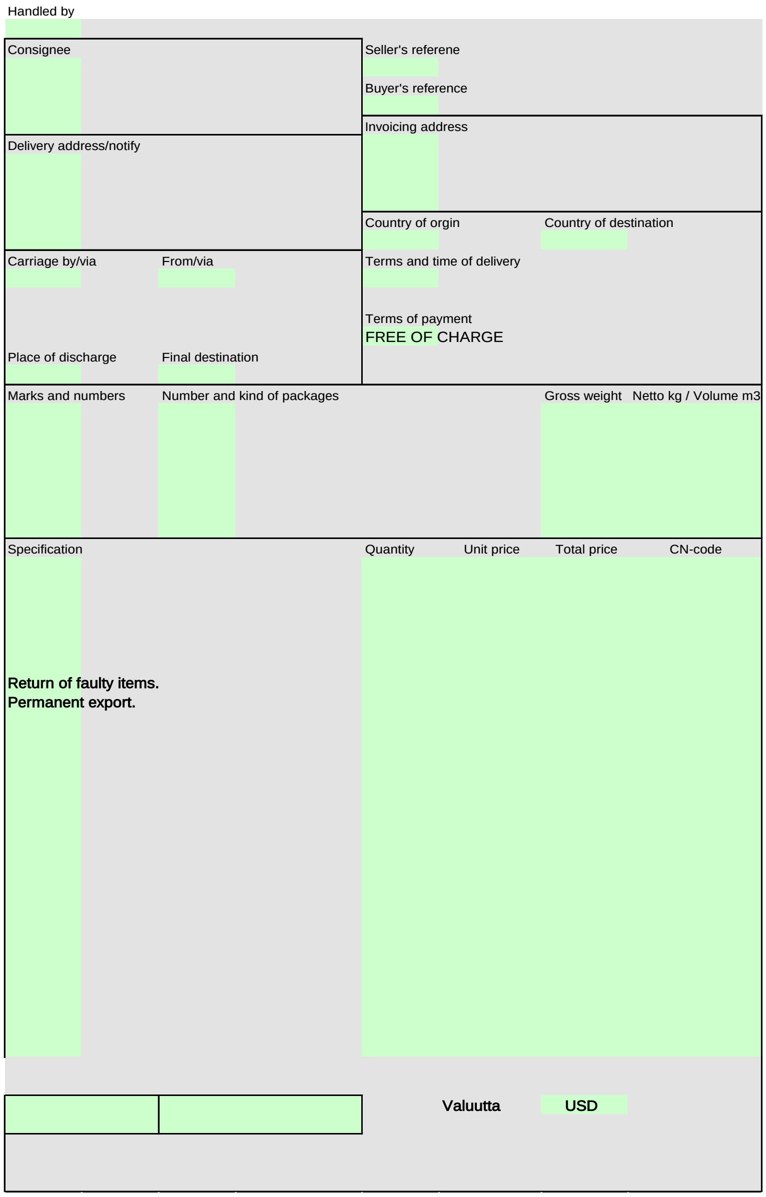

Handled by
Consignee
Seller's referene
Buyer's reference
Invoicing address
Delivery address/notify
Country of orgin
Country of destination
Carriage by/via
From/via
Terms and time of delivery
Terms of payment
FREE OF CHARGE
Place of discharge
Final destination
Marks and numbers
Number and kind of packages
Gross weight
Netto kg / Volume m3
Specification
Quantity
Unit price
Total price
CN-code
Return of faulty items.
Permanent export.
Valuutta
USD

Figure 40. Packing List and Proforma Invoice base.

According to field interview it takes approximately 5 minutes to enter all valid information to excel form. This particular function is only required for electrical products and it is carried out by in-bound logistics coordinators. The cost of labor is 23.45 € per hour. Hence the cost of task per complaint is 1.95 €. Cost calculations are illustrated in below figure 41.

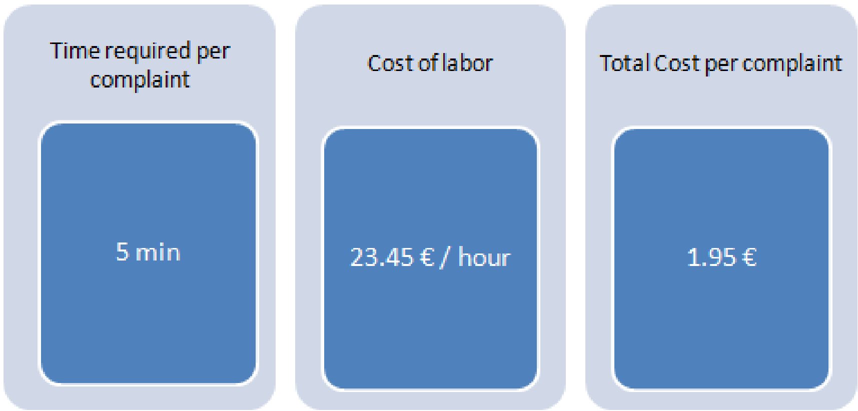


Figure 41. Cost of filling packing list and proforma invoice.

Packaging

Packaging process and material usage differs significantly for mechanical and electrical complaints and hence those are discussed separately. Following figure 42 presents the costs associated in packaging process.

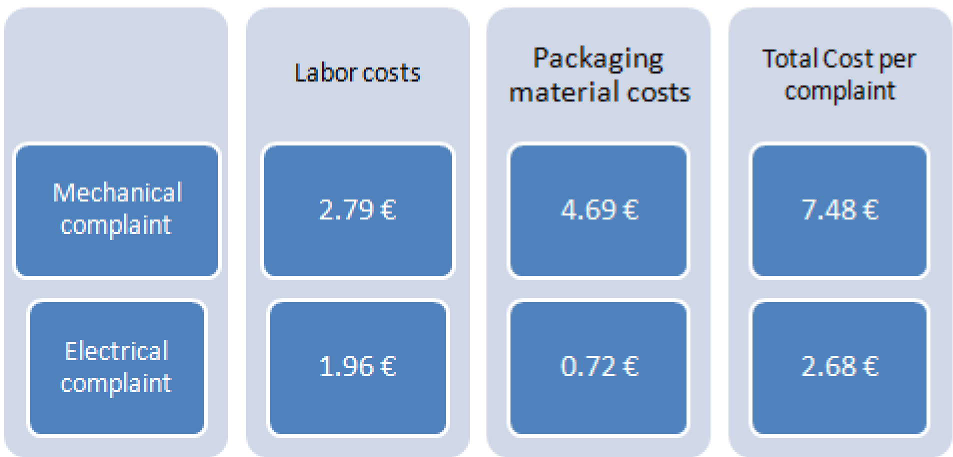


Figure 42. Costs of Packaging mechanical and electrical complaint.

Mechanical components are mainly delivered in set boxes that are returned back to suppliers once those get empty. These set boxes are used to return defected mechanical components back to suppliers. Mechanical components that do not use set boxes are mainly returned on EURO pallets. In addition for laying the component on the EURO-pallet or in set box there is a need to print and fasten A4-paper signing that pallet is containing a complaint. As mechanical products are mainly returned via external warehouse there is also need to inform warehouse worker who can move the pallet via dispatch area to external warehouse. According to estimations this requires altogether 10 minutes. The hourly cost of labor is 16.75 € for internal and external blue collar employees. Thereby cost of labor for mechanical complaint is 2.79 €.

Mechanical products used set boxes and EURO-pallets when defected materials were returned back to supplier. According to field interview these pallets were returned either via external warehouse or the goods dispatch area. Case company has a pallet returning policy with some of its mechanical suppliers in which both parties keep book about the pallets delivered and returned. The supplier is then entitled to invoice the difference between the pallets delivered and pallets returned. Therefore the problem is to apply the cost of material for all the mechanical suppliers as there are different returning policies used. This can be avoided by agreeing pallet returning policies with suppliers and then taking account all returned pallets by returning those back to supplier via external warehouse. But as this is not reality at the moment the cost of pallets should only be applied to those mechanical component suppliers that are not already involved with pallet returning policies. This would lead to creating a COPQ formula for every supplier and would not be appropriate. To simplify the reality the cost of packaging material used will be applied to all mechanical suppliers in amount of one EURO pallet that is approximately 4.69 €. Hence the total costs of packaging for mechanical complaint are 7.48 €.

In order to find appropriate information to packaging procedure of electrical components interview with packaging department took place. As packaging procedures are different for different suppliers also the packaging instructions are determined supplier specifically. According to packaging department electrical components are packed in layers and specific cushion is placed on top of the layers in order to protect the electrical products. Responsible in-bound logistics coordinator provides packaging department with complaint notes and pre-filled packing lists. Complaint notes are placed in packing boxes on the top of the products before closing packing boxes. Packaging department then fills all required information such as E-number, weight, volume in case complaints are returned to countries where customs clearance is needed.

The time needed to pack electric products into carbon boxes is based directly on the amount of complained products and also on package material used in packaging as the larger the packaging material and more the material needed to package the more cushion is needed to prepare and lay on products. According to the interview it takes approximately seven minutes to package complaint including electric products. The labor cost of packaging department employee is estimated to be similar as other blue collar employees. Hence the cost of labor is estimated to be 16.75 € per hour and hence the labor cost is 1.96 €.

In addition to the labor needed in packaging process also packaging material need to be taken in account when calculating cost of poor quality of component quality. There are two different packaging materials used that are material codes 68339332 and 3AUA0000019884. Current price for 68339332 is 56.15 € per 100 pieces and for 3AUA0000019884 is 71.82€ per 100 pieces. Among those two box 3AUA0000019884 which is 400mm*300mm*320mm is the one used most commonly. Therefore in order simplify the actual situation it will be applied to the packaging material calculations. Therefore 0.72 € will be added to electrical complaint process as material costs. However, the amount of cushion used in packaging process changes every case therefore it seems to be quite hard to expand cost of poor component quality to include the cost of cushion. Hence, the total cost of packaging for electrical complaints is 2.68 € per complaint.

Forwarding

According to the field interview the time needed to fulfill forwarding functions changes practically in every shipment but approximately it takes between 10 and 15 minutes if all required information are gathered. Among these required information are packing list that is first pre-filled by in-bound logistics department and then packaging department have added more information to those such as mentioned in previously. This information is used when making dispatch note and customs clearance. Forwarding department needs also customs code (HS code) and certificate of original country if material returned to the country where customs clearance is needed. In addition CR-number is required for complaints that are to be returned to China. Forwarding costs are calculated using ABC-methodology and presented in below figure 43.

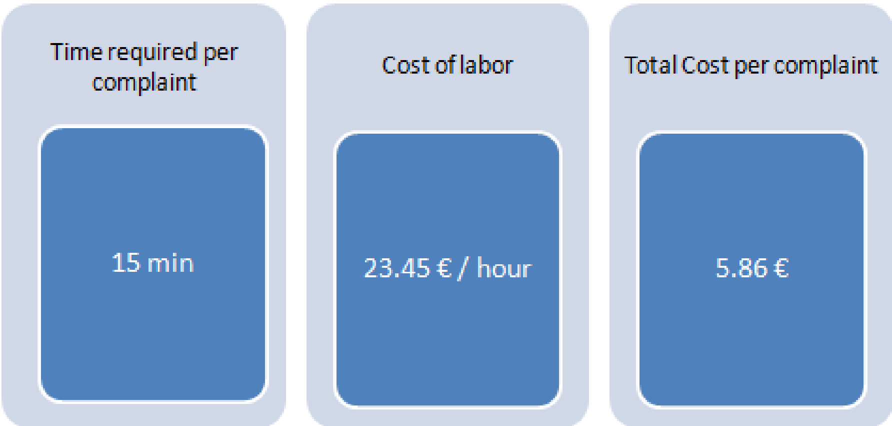


Figure 43. Forwarding costs per complaint.

The time required to fulfill all the forwarding functions is 15 minutes in cost of poor component quality calculations. Employees at forwarding department are white collar employees and hence the labor cost of hour is 23.45 €. Thereby the cost of forwarding functions per complaint is 5.86 €.

Delivery to external warehouse

Mechanical products needs additional transportation as those needs to be first delivered to external warehouse from where the actual delivery to supplier is organized. Thereby information about service is gathered by interviewing the in-bound logistics coordinator responsible for service. It needs to be noted that this external service provider has three trucks in different routes within case company and its external warehouses. However, only one route, which is between the external warehouse where the materials for module production is stored and case company's factory, is studied more closely. In addition only truck number 47 is observed in order to gather cost information. Following figure 44 presents the costs associated delivering mechanical complaint to external warehouse.

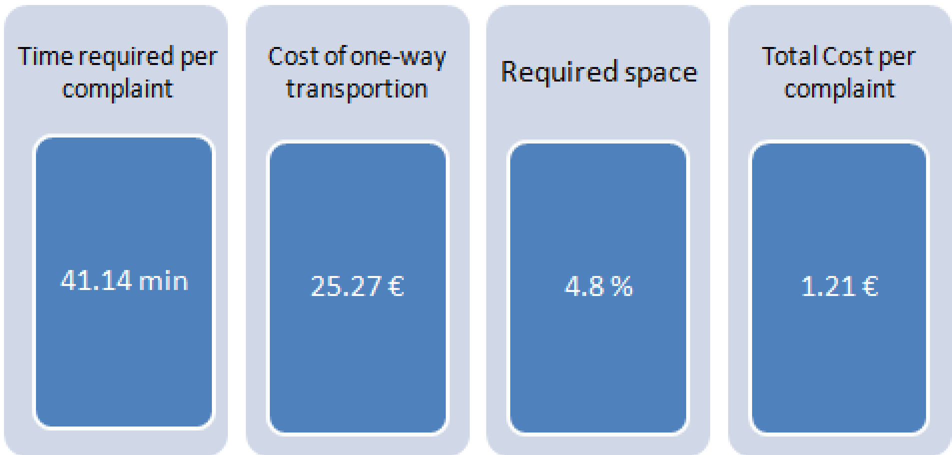


Figure 44. Costs of delivering mechanical complaint to external warehouse

According to the information gathered from interview truck is able to transport materials from 5 to 7 times back and forward between case company factory and external warehouse per 8 hour shift. The amount of transportation is dependent on the time required to load and unload the truck and thereby the amount of materials required to move between these locations determine partly the amount of transportation. In addition also road traffic can significantly influence the time required to transport materials. If observed truck is able to deliver materials back and forward 5 times per shift the time required to load, transport and unload is 48 minutes and if truck is able to transport 7 times back and forward the time required for same activities is 34.29 minutes. As there is not information available about frequency of each possible outcome the best solution is to apply the average of those two outcomes described earlier. The average time required loading the truck, transporting the material and then to unload the truck at destination is thereby 41.14 minutes. The cost of service including hourly salary and truck costs is 36.85 € per hour. Hence the total cost of one way transportation is 25.27 €.

However, it needs to be noted mechanical complaint occupies only a small part of space in truck and hence cost of transportation should be calculated per that space. The truck holds 19.92 square meters of area as load area of truck is 8.3 meters long and width is 2.4 meters. Mechanical complaint is packed in set box or on EURO-pallet. The actual size of set boxes changes according the material needed to be delivered but in calculations it is considered to be sized as normal EURO-pallet having dimensions of 1.20 meters and 0.80 meters. Hence the area that mechanical complaint occupies in truck is about 4.8 % if pallets cannot be loaded on each other and its share of costs is 1.21 €.

Physical returning of defected materials

The process of physical returning of defected materials is also different for mechanical and electrical complaints and hence discussed separately. The costs associated with both processes are presented in below figure 45 and described more carefully within this sub-chapter.

	Time required per complaint	Average cost of labor	Total Cost per complaint
Mechanical complaint	15 min	16.75 € / hour	4.19 €
Electrical complaint	5 min	23.45 € / hour	1.95 €

Figure 45. Cost of physical returning of defected goods

Complaints are sent from case company to external warehouse to wait the approval that those can be sent back to suppliers. In-bound logistics coordinators give approval by sending e-mail in which complaint notes are attached. Then the actual material is verified to be according to the complaint note. Material logistics team is informed in case that actual material and the material entry in complaint note are different. Only after complaint notes are sent to external warehouse and materials are verified to be correct can those be returned to suppliers. Complaints are returned mainly among other return deliveries from external warehouse to suppliers. Therefore every complaint needs to be entered into consignment note. It takes approximately 15 minutes to return mechanical products. As the labor is carried out by external blue collar employees the labor cost per hour is estimated to be 16.75 € per hour and hence the cost of physical returning of defected goods for mechanical complaint is 4.19 €. According to the field interview in addition to the process described above there are also complaints that are returned on weekly basis. The purpose with these complaints is to collect as many defected materials as possible from same supplier and then to do deliver those at once.

Time required for electrical products is estimated to be 5 minutes as those materials needs to be only delivered to areas where external service provider that is responsible for delivering materials back to supplier is able to pick those up. In addition required paper documents need to be within materials so that external service provider is able to combine electrical complaint delivery. This particular task is carried out by forwarding department having white collar employee hourly cost of 23.45 €. Thereby the cost of physical delivery for per electrical complaint is 1.95 €.

Cost of complained material

The direct cost of material for all the component categories is mainly cost of complained material. However, this particular evaluation of costs poor component quality does not include cost of complained material for two special reasons. Firstly, the cost of component depends on material and as case company purchases thousands of different components the price is variable. Therefore it is impossible to set a fixed price of material cost for formula that is evaluating the cost of poor component quality. Secondly, case company is really precise about their component quality. Therefore the price of nonconformance in terms of price of purchased material is always been requested to be credited or repaired by suppliers. Therefore if this particular formula would contain the price of direct material it would lead to situation in which the price of purchased material would exist twice. Having these two reasons in mind this paper notes that the direct material costs should be involved in evaluation of cost of poor component quality but as it is already involved in complaint process it should not be involved in this additional evaluation of COPQ.

Transportation

In-bound logistics coordinators are responsible for purchasing materials for production. As amount of stock is reduced by the number of complained products this indicates that compulsory materials need to be purchased in order to keep the stock levels at appropriate levels. In most of the cases the amount of material complained is not significant and therefore there is not a need to place a purchase order just after a complaint process but in-bound logistics coordinator purchase additional products according to the amount of stock and time needed for delivery. In some cases however the proportion of defected material presents most of the material in stock and therefore there is a need to purchase material that need to be delivered fast for production. The price of delivery will be paid by case company and therefore it should be taken in considerations of cost of poor component quality.

In order to simplify the actual situations some of the estimations will be applied when calculating the cost of transportation. Firstly, the case company has different agreements in terms of delivery with suppliers ranging from Exworks to DDP. However, the price of transportation will be applied similarly to all suppliers. In addition it needs to be noted that price of transportation depends mainly on geographical distance between supplier and case company but as the purpose is to create a formula that would be suitable for all suppliers the cost of transportation will be calculated based on actual transportation costs from chosen example supplier.

It needs to be noted that space needed delivering mechanical products is huge compared to electrical components. However, the cost of transportation per cubic meter is much more expensive for electrical components as those are delivered mainly from Far-East. As the difference between mechanical products and electrical products has been applied already it is appropriate to apply this also when calculating costs of transportation. The cost of transportation is illustrated for mechanical complaint and electrical complaint in following figure 46.

	Size	Cost	Total Cost per complaint
Mechanical complaint	0.25 pallets	41.60 €/pallet	10.40 €
Electrical complaint	0.0384 cbm	362.00 €/ cbm	13.90 €

Figure 46. Cost of transportation.

Mechanical complaints are packed either on set boxes or on EURO-pallets. The size of set boxes is based on the products that are delivered within it. In order to simplify the actual situation the cost of transportation is based on the size of EURO-pallets. It is also estimated that mechanical products that needs to be purchased to compulsory to those that were complained do not fulfill whole EURO-pallet but only proportion of it and hence the cost of transportation is calculated for one quarter of EURO-pallet. The price of transportation is based on actual costs of supplier locating in eastern part of Estonia. Cost of transportation per complaint is calculated by multiplying the proportion of EURO-pallets and transportation costs per EURO-pallet. Using this formula gives 10.40 € per mechanical complaint.

The average electrical complaint delivery is packed in carbon box 3AUA0000019884 that has size of 400mm*300mm*320mm. It was decided to use air freight in cost of transportation calculations as most of electrical products are delivered by air. In addition in case of complaint there is a need of acquiring compulsory material as fast as possible and therefore it is appropriate to apply faster but more expensive transportation method. Therefore the average flight costs from China to Helsinki factory are investigated. The average transportation price per complaint can be calculated by multiplying the size of complaint package in cubic meters and the transportation costs per cubic meter. This formula gives 13.90 € for electrical complaint.

7.1.5 External Failure

Interview with steering group indicated that a proportion of defected components are not currently found using appraisal done by assemblers and testing systems. Therefore some end-products with defected components are delivered to customers. In order to capture external failure costs of poor component quality it was investigated how much would a common field defect cost to case company and how often a field failure occurs in proportion of all complaints. According to the field study almost all field failures that are occurred because of component defect are related to electrical component problems. Interviews indicated that last field failure that came true because of mechanical component occurred in 2009. Although that particular incidence was rather epidemic in magnitude, any generalizations that external failure would also concern mechanical products seems to be irrelevant. Hence, external failures are only examined for electrical complaints. Following figure 47 presents how cost of external failure is calculated for electrical complaints. Calculation principles are discussed open in this sub-chapter.

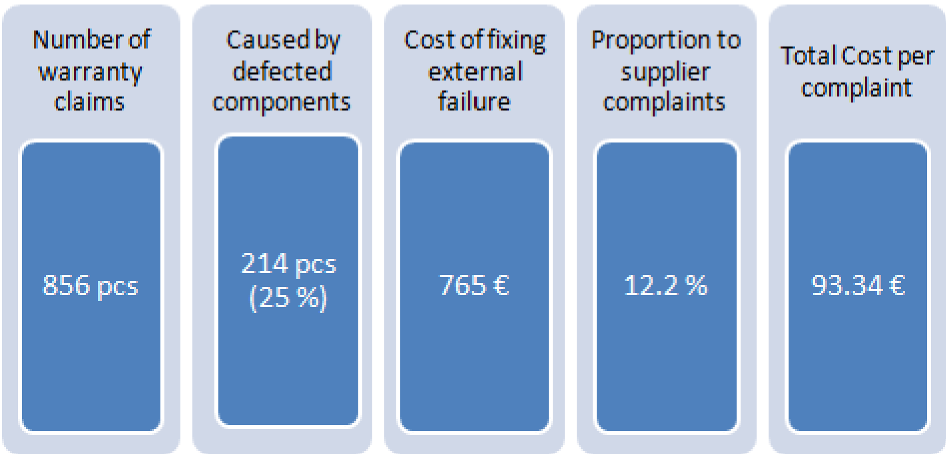


Figure 47. Cost of external failure per complaint

According to product engineering department selected department has received approximately 107 warranty orders weekly in year 2011. This amount includes only end-products that are under responsibility of Helsinki factory and therefore those figures that are under China and USA are excluded. It needs to be noted that this particular figure is not directly related to Helsinki factory production as it includes two contract manufactures that are producing end-products under Helsinki factory. This seems to be rather high figure but as selected department delivers approximately 13 500 end-products weekly the defected rate is only 0.8 %. When amount of weeks per month is assumed to be exactly four, the amount of monthly warranty orders is 428. In addition it needs to be noted that selected department represents approximately halve of case company's sales and hence the total number of complaints with similar costs can be estimated to be 856 per month as the first pillar in figure 47 illustrates. This estimation is quite valid as although rest of the factory have less external failures the cost per case is essentially greater because of the size and comprehensively of their end-products.

Interview with product engineering responsible for warranty claims suggest that external failures consist of three categories. Most of the external failures presenting up to 70 % of all external failures are based either on failures in design or usage environment. The second largest group that presents 25 % of all external failures is derived from defected component used in end-product and 5 % of external failures are conducted because of misuse of end-product by customer. Therefore the amount of supplier related external failures is 214 pieces monthly as the second pillar of figure 47 indicates. This is calculated by multiplying the percentage of external failures that are derived from defected component used in end-product with amount of monthly warranty orders the supplier related external failures.

Warranty costs are estimated to be altogether approximately 1.9 million Euros in 2011 and approximately warranty cost per case would then be 240 €. It needs to be noted that most expensive warranty cases including HPD and NVPI warranty orders are excluded from this investigation. Calculated warranty costs includes only spare parts excluding all the costs any costs at destination. The cost for fixing the problem varies according to the country were problem is occurred and wideness of the problem. Operational Excellence department had had a study about the costs which indicates that it costs approximately $687.75 to correct a problem at destination. Correcting a problem includes sending maintenance man to destination and accommodations. Local sales company is responsible for those costs but these are included in external failure costs. There is static change rate between euro and dollars used in quality programs is 1.31. Therefore it is appropriate to apply this change rate also in this study. When using the change rate of 1.31 to $687.75 that would account for 525 € and total costs for external failure is 765 €. This is illustrated in third pillar of figure 47.

As the external cost per field complaint is determined the next phase is to determine the frequency of supplier related field failures in proportion of all failures. Therefore the cost of external failure can be applied into cost of poor quality. In was investigated in complaint process that in November 2011 the amount of supplier complaints are 1754 and the amount of supplier related external failures is about 214 monthly. Therefore supplier related external failures represent approximately 12.2 % of all found failures as illustrated in fourth pillar of figure 47. Poor supplier component quality has therefore external failure cost of 93.34 € that is calculated by multiplying the frequency of supplier related external failures with the cost of external failure.

7.1.6 Overview of poor component quality costs

In the beginning of this sub-chapter the cost per mechanical and electrical complaint were decided to examine separately as those have dissimilar costs. This particular decision seems to be appropriate as examination of cost factors supports that mechanical complaints and electrical complaints have dissimilar costs. Cost per complaint for mechanical complaint is 55.63 € that is about 70 $ when exchanged to comparable currency. The structure of how this particular cost consists is presented in P-A-F model in figure 48.

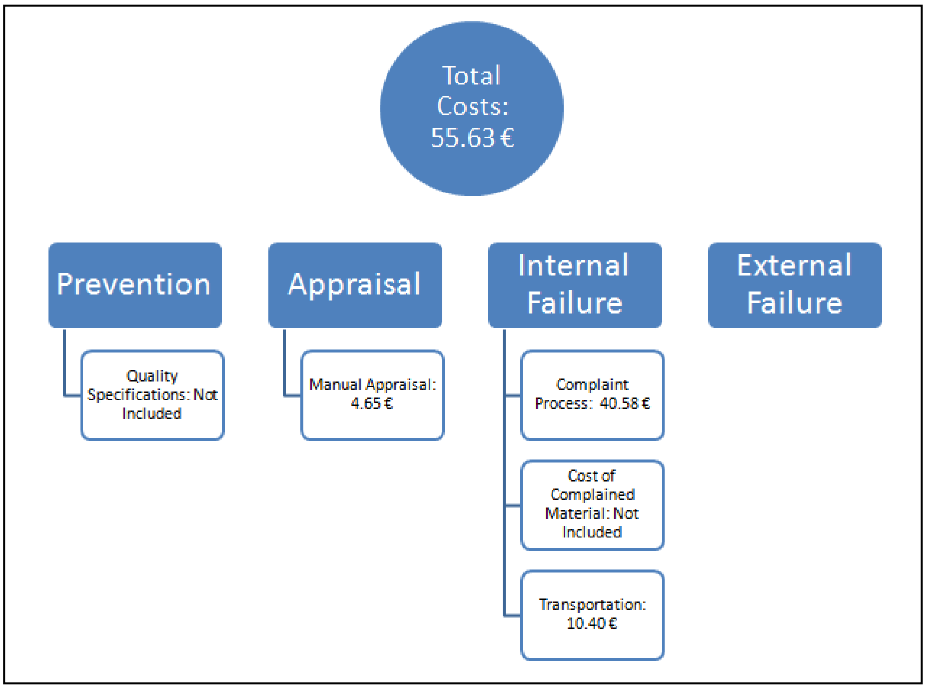


Figure 48. Cost of mechanical complaint

The cost of poor supplier component quality of electrical complaint is significantly greater than for mechanical complaint mainly because its cost structure includes external failures and appraisal at electrical testing system. In addition to those identification of electrical problem requires more time and laboratory resources which are rather expensive. The cost per electrical complaint is 183.97 € that is about 240 $ when exchanged to comparable measurement unit. Figure 49 illustrates cost of electrical complaint in P-A-F model.

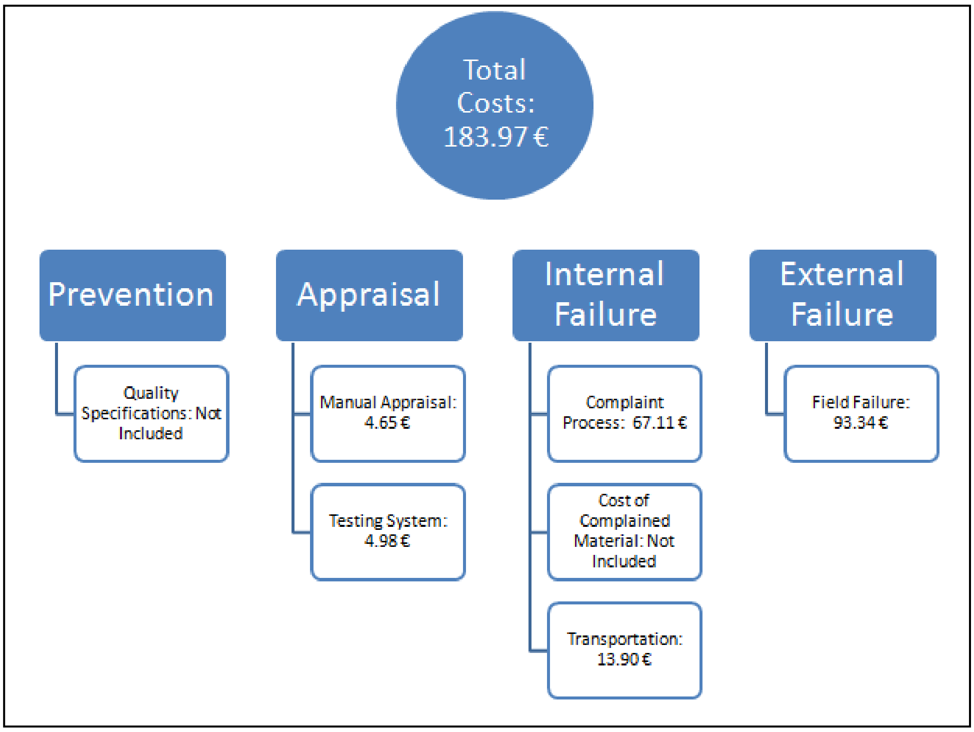


Figure 49. Cost of electrical complaint.

7.2 Availability

Availability is rated in case company using two subcategories that are on-time-delivery performance and buffering performance. Literature review did not provide any direct resolution about how such items should be evaluated in terms of cost of poor quality. However, chapter 4.3.2 determined that cost of poor quality should be analyzed on based on baseline that could be historical or goal set by management. Also chapter 3.3 presented Quality Loss Function, QLF that gives quite good picture that costs of poor quality does not have to be based on activities but those can be also evaluated using simple mathematical equation. It needs to be noted that the QLF is designed for three different type of categories from which larger-the-better is most appropriate calculating cost of poor quality for availability. Before calculating cost of quality for availability it is crucial to study how poor supplier buffering performance and poor supplier On-Time-Delivery performance affects case company. This is illustrated in following figure 50.

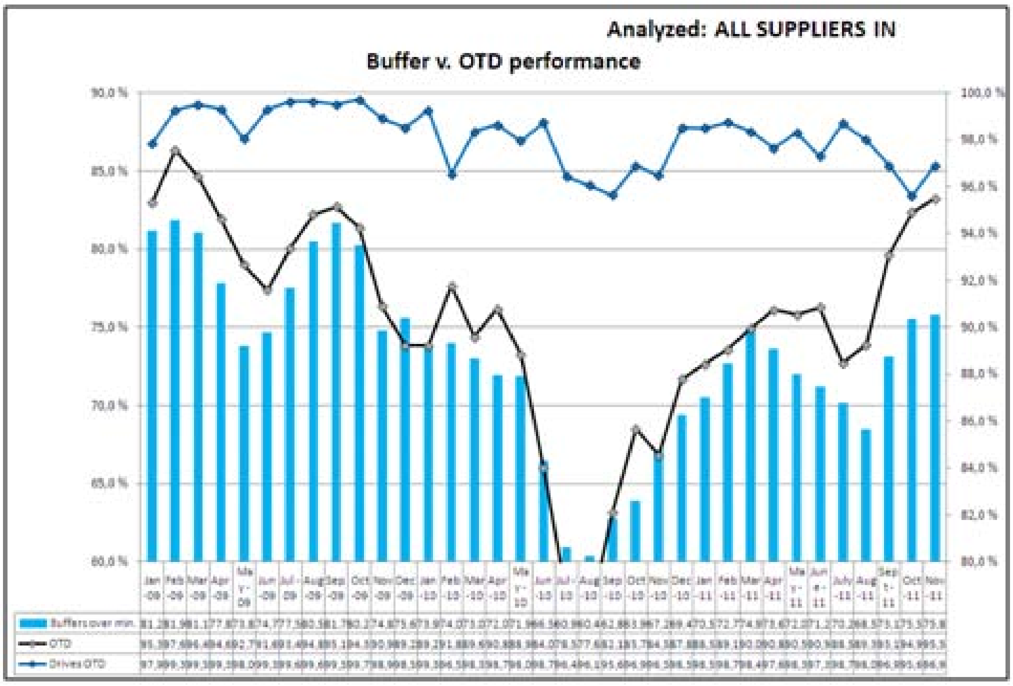


Figure 50. Supplier buffering and On-Time-Delivery performance

Above figure 50 presents supplier buffering performance (light blue pillars), supplier on-time-delivery performance (continuous black line) and case company On-Time-Deliver (continuous blue line) between January 2009 and November 2011. The purpose of this figure is to indicate that supplier buffering performance is a root cause for supplier on-time-delivery performance. These in fact have an effect on case company's production and therefore also on on-time-delivery performance.

Above figure indicates that supplier buffering performance is a cause measurement and supplier On-time-delivery is an effect measurement. Hence, there is no reason to investigate two separate categories but it is most appropriate to combine those and to investigate only effects of poor supplier On-time-delivery performance. In addition this indicates that most appropriate way to find out true costs of poor supplier OTD is to study how late deliveries affect case company's production and OTD.

7.2.1 Description of cost elements

The purpose of this sub-chapter is to investigate how poor availability has an effect on case company. According to interview with Operational Excellence team manager the costs of poor supplier On-time-delivery varies greatly. As mentioned earlier, on-time-performance is measured in supplier performance rating only with two alternatives that are “On-Time” and “Late”. Hence this particular measure does not indicate how late individual purchase order line (POL) is. In addition, true quality costs of delivering late an individual POL depends directly to the amount of stock on hand. In case that supplier is unable to deliver particular products that are already out of stock it would automatically stop one or more production lines. According to the interview direct quality costs for whole production not running is 47 500 € per hour. In the other hand other deliveries can be easily late for many days without any true quality costs to occur as there is enough material in stock for production needs.

According to the previous description it is obvious that poor quality cost of poor supplier on-time-delivery performance should be examined per purchase order lines. It seems to be appropriate as on-time-delivery performance is calculated by dividing the amount of POLs that are supplier has delivered on time with all POLs that supplier has delivered within the time period. Furthermore this particular decision to examine cost per POL allows this quality cost calculation method to be implemented in other quality cost projects such as in FLOP10.

As the quality cost of poor supplier OTD performance varies according to the stock levels of case company it is quite obvious that estimate for quality cost per late delivery needs to be determined. According to the interview with in-bound logistics department, that is responsible for purchasing material, case company has a risk policy that determines the amount of safety stock that needs to be at factory at all times. Hence the possibility for any disturbance to occur in production is rather small. Respondents at in-bound logistics department seem to agree this assumption. Hence, the cost of late delivery is estimated to be 150 € per POL. Although, this assumption is chosen for this master thesis future actions of case company should include determination of true costs of late delivery. This should be calculated by first calculating all the costs caused to case company during determined time and divide this with the amount of all POLs delivered by suppliers during this time.

In addition to the cost of late delivery per POL the target value of supplier OTD performance is decisive factor. In most cases the target value for supplier on-time-delivery performance has been 100 %. In addition, it needs to be noted that in FLOP10 quality project the target level of supplier OTD performance has been set to 98 % level and in the supplier performance rating suppliers are given rating points only after they outperform limiting value of 80 %. Hence, it seems to be appropriate to create two alternative QLFs and to empirically find the one that is most suitable for the needs of case company. In the first Quality Loss Function the target is set to 100 % level but the approval level is on 98 % level. In the second Quality Loss Function the target is also set to 100 % but the approval level has been decreased to 80 % level.

7.2.2 Applying QLF

Quality cost can be calculated by using Quality Loss Function as it seems to be most appropriate method for calculating the costs for products and services for which the distance from previously set quality target determines the quality costs. In addition it needs to noted, that these costs that are calculated using QLF includes hidden costs.

Quality costs will be calculated in this paper using nominal-the-best quality attribute as although quality attribute that seems to follow larger-the-better quality attribute it has maximum value of 1 (100 %). In addition, it needs to be noted that the objective value for larger-the-better quality attribute is infinite. Thereby, nominal the best quality attribute is the most appropriate for calculations. The formula for quality loss calculations is hence following:

, in which

L = Quality Loss in Euros
k = Cost Coefficient
y = Output Value of Quality Characteristic
m = Target Value of Quality Characteristic

Alternative 1

The purpose of the first phase of quality loss calculation is to determine the level of *Cost Coefficient (k)*. This can be calculated by simply placing predetermined values in formula in a way that the cost coefficient is the only variable left in function. Quality Loss in Euros per purchase order line is set to 150 €, target value of quality characteristic is set to 1 (100 %) and output value of quality characteristic is set to 0.98 (98 %) therefore the function can be written and solved following:

The purpose of the first phase was to solve the variable cost coefficient (*k*) so that function can be used in a real life calculating the quality costs in supplier performance ratings. The current form of formula is presented below:

The cost per purchase order line can be now calculated by first calculating the average supplier on-time-delivery performance percentage and then to place this into equation where *y* is now located. This particular calculation informs the average cost per POL that supplier has caused because of its on-time-delivery performance. Following figure 51 presents how quality costs per POL increases as the average supplier on-time-delivery performance decreases.

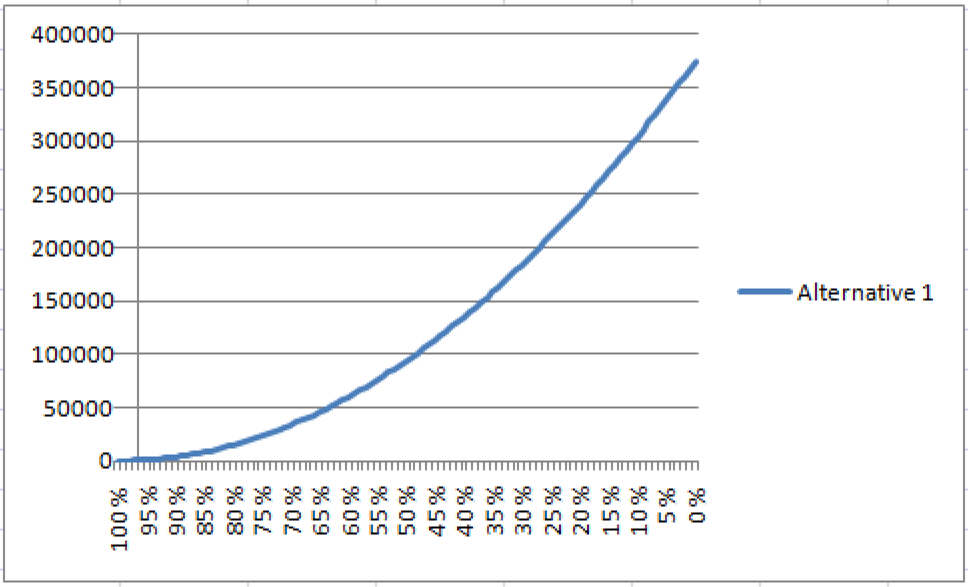


Figure 51. Alternative 1

Above quality loss function indicates that the cost per POL increases from zero up to 375 000 € as the supplier-on-time delivery performance decreases.

Alternative 2

The calculation of second alternative will be carried out similarly as the first alternative. Hence, value of cost coefficient *(k)* will be determined firstly using predetermined values:

- Quality loss in Euros (L) is 150 €
- Output value of quality characteristic (y) is 0.80 (80%)
- Target value of quality characteristic (m) is 1.00 (100 %)

Therefore the equation can be written and solved following:

The value of cost coefficient will be applied in second phase in which real quality costs of suppliers' on-time-delivery performance are calculated. Second alternative suggest that formula for those calculations would be following:

Above equation can be used simply by first defining the average costs of supplier on-time-delivery performance per purchase order line. This can be calculated by first defining on-time-delivery performance of supplier by dividing the amount of purchase order lines that are delivered on-time within time period with the amount of all delivered purchase order within time period. This amount will be changed from percentage mode to basic number mode and is placed where y is located in above equation. Then this information is applied when calculating the average cost of on-time-delivery performance per POL that is presented as L in above function. The total cost of on-time-delivery performance can then be calculated by multiplying the total amount of POL delivered within time period. This makes scalability of the function possible. Following figure 52 illustrates how average cost per POL increases as on-time-delivery performance decreases.

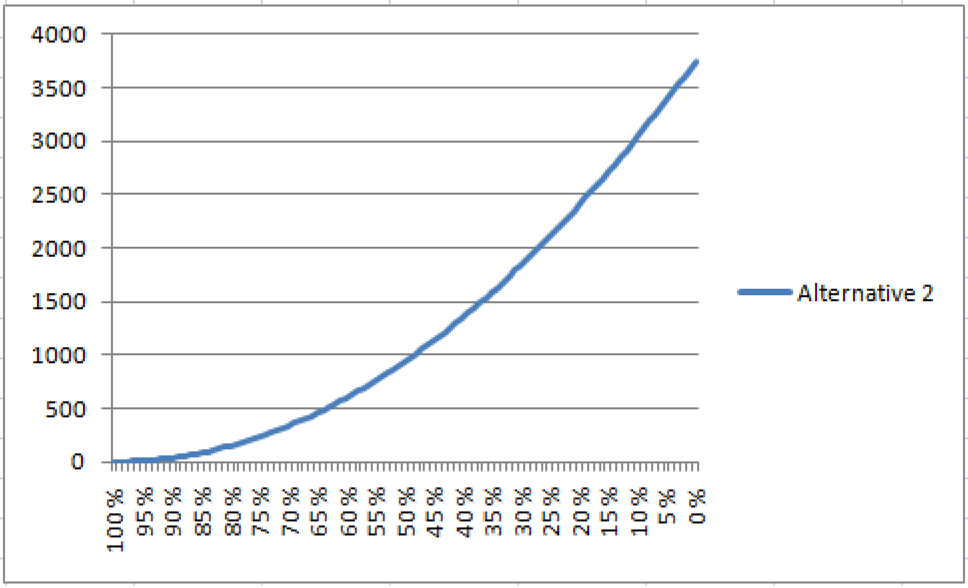


Figure 52. Alternative 2

Previous figure 52 indicates that costs per POL increase from zero to 3 750 € as on-time-delivery performance decreases from 100 % to 0 %.

7.2.3 Overview of on-time-delivery costs

At this point two different alternatives have been created for calculating on-time-delivery performance. Therefore the purpose of this sub-chapter is to determine which of previous alternatives is most suitable for supplier performance rating.

Comparison of these two alternatives indicates that costs are developed 100 times in alternative 1 than in alternative 2. Thereby, quality costs at on-time-delivery level of 90 % is 3 750 € per POL for alternative 1 and 37.50 € per POL for alternative 2. In imaginary example in which supplier would have delivered 1000 POLs within last quarter the related quality costs would be 3 750 000 € with the alternative 1 and 37 500 € with the second alternative. The costs that alternative 1 suggest that on-time-delivery performance would have at 90 % performance level is the same that alternative 2 suggests at 0 % performance level. The costs that alternative 2 suggest seem to be more appropriate than the costs that the alternative 1 suggest. Hence the model chosen for calculating on-time-delivery costs is the one that is presented in alternative 2.

8 CONCLUSION AND RECOMMENDATIONS

8.1 Validity of measures

This first subchapter discusses how decisions made at case company might affect on measures of amount of supplier complaints and on supplier on-time-delivery performance.

Supplier component quality

According to the field interview with in-bound logistics coordinators design of case company’s products will very much determine the qualities of suppliers’ products. Therefore case company is very much involved not only within suppliers’ product design process but also provides some of the production and measuring tools to suppliers. These tools are actually owned by case company and suppliers are only borrowing those while providing components to case company. One of the drawbacks in current complaint process according to field interview is that all complaints are supposed to be suppliers fault without any consideration of root cause of the component problem as it was highlighted in some cases it seems that the root cause was because of impropriate state of case company owned production tools used by supplier.

According to field interview with product engineering team working in laboratory it was highlighted that one of the significant reasons for quality risks is that in some cases case company does not set specific quality requirements to components used in electrical items but only specifications of used components and also the source of supply is provided to supplier. This will lead to situation in which components used in electrical items might have higher risk of having quality problem when comparing in illustrative case in which those quality requirements would have been given to supplier.

Case company's current global purchasing strategy is based on principle that certain amount of material need to purchased from emerging markets. This particular decision is based on assumption that this particular strategy would lead to cost savings. Field interviews however highlighted that co-operation with suppliers that are located in mature markets is straightforward and functions well. However, some of the persons that were interviewed believed that co-operation with suppliers functioning in emerging markets would not be as efficient because of cultural differences. This is factor that needs to be noted in complaint process as it is evaluated to be critical factor when there is a need to receive results in terms of complementary supply or investigation of root cause of defected items.

It needs to be noted that the amount of complained components might not provide all the costs of poor component quality as greater quality problem will lead to investigation not only of those products that are actually defected but also those that are delivered to case company within same batch. Therefore there is need to investigate all the products in case company factory but also in external warehouse. In some cases this will lead to extensional amount of additional work in terms of dividing components into those that need to be complained and those that can be used in production. In terms of quality costs calculations this amount can be hard to be evaluated as there is not valid information valid at the moment. The amount of additional work has been estimated in this master thesis but as the estimation is only based on interviews it might represent inappropriate magnitude. Field interviews with material logistics team however indicate that substantial amount of direct labor is needed to investigate possible defected products in times of greater quality problem therefore this time ought to be monitored more carefully in the future so that these costs would be allocated as part of cost of poor quality.

Supplier on-time-delivery performance

Supplier-on-time performance is measured automatically as case company's ERP system collects information about asked delivery dates and actual delivery dates of purchase order lines. As the functionality of the measurement is rather simple it would be supposed that system would be rather reliable. However, the interview with inbound logistics coordinators does not support that claim but vice versa it indicates that system's reliability has serious drawbacks. In these situations there is a time gap between the times that goods are actually receipted with the time that goods are receipted in ERP system. In this kind of situation the measure of supplier on-time-delivery performance does not represent the true on-time-delivery of supplier.

In addition to previous there are two other occasions in which the on-time-delivery date might be affected in ERP system that case company is using. In the first situation supplier has asked to amend the delivery date but for some reason responsible inbound logistics coordinator has forgot to do this alteration in ERP system. In many cases this kind of course of event occurs in ramp up projects in which new material is being purchased to new future end-products. These ramp-up projects are problematic as in many occasions the material that is being purchased is altered while purchase order is already sent to supplier. The second case that may inflict problems is a situation in which the price of purchased material need to be revised after the purchase order line is receipted in the system. In this kind of situation the goods receipt of the purchase order line need to be first cancelled. The second step fixing the problem is to determine the correct price for the purchase order line and then to make goods receipt once again manually. The third step in this case is to determine the statistical delivery date for the day that this alteration occurred. In many occasions this third step of fixing the problem is somehow forgotten and therefore the on-time-delivery performance of supplier is accidently damaged.

8.2 Reliability of calculations

Reliability of calculations is examined in this sub-chapter. Both categories, cost of poor supplier component quality and cost of poor supplier on-time-delivery performance, are discussed alongside as the main reliability of calculations is based in both cases on estimations applied.

According to the Hughes et al.1998, p.194 there is a tendency in organizations to leave measurement schemes in place and unchallenged after those have been implemented. They emphasize that all measure schemes require regular update and amendment as causal measures have a limited life. Hence, calculations carried through this master's thesis are only valid in current environment and any change in environment will also affect reliability of calculations.

As mentioned above the use of estimates is one of the main factors that could affect the reliability of both calculations. Lot of estimates was applied when cost of poor supplier component quality was calculated. The main reason for using estimates is that there was no valid information available or that use of resources fluctuate every case presenting a wide spectrum of possible values. Hence, the use of estimates provide a mean for continue the project. Estimates are based on interviews in which information were gathered from employees that are responsible for particular processes. This indicates that the best information available was used in master's thesis and thereby calculations are as correct as those can be. Author of this thesis however, highlights that cases where estimations were used those should be re-examined in order that case company would acquire more specific information and possible amend current results. This was not possible during the master's thesis as time was constricting factor during the project.

When calculating cost of poor supplier on-time-delivery performance there were two estimates that are quality loss per purchase order line and accepted deviation from target value. The latter of those two has been quite relevantly determined to be chosen correctly. Therefore estimation used for quality loss is the only estimation in this master's thesis that is not based on justifiable consideration. Hence, the justification of correct average quality loss per purchase order line is given as responsibility to case company. In addition to the estimation used in quality loss function, the applied function itself might not represent true cost of on-time-delivery performance. This particular function is designed mainly for calculating quality costs of mechanical products that might have deviation in their design. However, used QLF methodology illustrates that cost per purchase order line increases as supplier on-time-delivery performance decreases. This particular ideology is supported by case company.

8.3 Comparison to previous models

The purpose of this sub-chapter is to compare results of this master's thesis with the preview procedures of case company. The comparison is made mainly between the discoveries of this study and methodology applied in FLOP10 quality project as currently supplier performance rating does not include any transformation from operational measurement unit to monetary unit. Supplier component quality will be discussed first which will be followed with the supplier on-time-delivery performance.

Supplier component quality

FLOP10 quality project is designed to measure quality costs of worst 10 suppliers of case company. Measurement is based on comparison with monthly quality cost figures with baseline. Current baseline is build for every chosen supplier in a way that the amount of complaints and on-time-delivery performance percentage value represent monthly average values from previous operating year. Monthly deviation from baseline is seen either as savings or as additional costs.

The main correction in finding of this master's thesis with previous model in terms of cost of supplier component quality is differentiation from having only one cost for complaint to have different costs for mechanical and electrical costs. In FLOP10 project quality costs of poor supplier component quality is calculated with estimated complaint cost which is $ 165 per complaint in spite of whether the processed complaint is mechanical or electrical. Findings of this paper propose that component quality cost for mechanical complaint is about $ 70 and approximately $ 240 for electrical complaint.

Proposed model seems to be sensible as examination of quality costs indicates clearly that mechanical complaints and electrical complaints have dissimilar costs. Hence, quality costs should be calculated with values that are related to actual quality costs and not with average costs as use of average costs will distort measured situation with the actual situation. Only one exception can be found as current FLOP10 suppliers include a mechanical supplier that delivers bulk material including mainly screws and nuts. In these situations cost per complaint should be calculated with amount of complaints instead of complained materials as that particular way would provide costs that are actually used per complaint.

This particular change can be implemented in a way that supplier is determined to be either a mechanical component supplier or electrical component supplier. This particular definition is possible as suppliers of case company seem to be genuinely either electrical or mechanical suppliers.

Supplier on-time-delivery performance

Currently costs of poor supplier on-time-delivery performance are dependent on actual on-time-delivery performance and stock value. Application of on-time-delivery performance is carried in a way that actual on-time-delivery performance is compared with the target on-time-delivery performance. The difference between those variables is prescriptive factor in equation applied currently. Stock value is calculated as determined percentage of value of materials that are purchased from this particular supplier and hold at case company's stock. According to the previous studies carried out in the case company the result of multiplying these two factors would give appropriate figure of monthly on-time-delivery costs.

The main difference with the model proposed in this paper with the previous model is that costs are not calculated monthly but per purchase order line in a way that cost per purchase order line is dependent on supplier on-time-delivery performance. Hence, total costs can be calculated simply by multiplying the average cost per purchase order line with the amount of purchase order line in specific time. In this way proposed model can be applied for different time intervals. Examination of supplier costs was carried out with information gathered in FLOP10 project and results of examination suggest that this particular cost calculation scheme seems to be appropriate in situations in which supplier has frequent deliveries to case company. Therefore, the model suggested in this paper seems to distort quality costs in cases that supplier is delivering quite rarely but in large quantities.

In spite of described weakness of the proposed model it seems to be more appropriate as current methodology for quality cost calculations as in dynamic business environment suppliers are rarely able to have an influence on value of materials that are hold at case company's stock. In addition, there should not be a link between the stock hold at case company and the on-time-delivery performance of supplier. On the contrary individual buffering agreements and logistic agreements are agreed between case company and suppliers in order that supplier would be able to provide needed material within delivery time.

8.4 Recommendations

Examinations of this master's thesis suggest that cost per complaint should be revised as proposed in this study. Current cost calculation scheme applied in FLOP10 project measures cost per complaint with average complaint cost. This particular method seems to distort actual component quality costs. Hence, it is recommended to amend this particular poor quality cost calculation method directly in a way that mechanical suppliers will have cost of $70 and electrical suppliers cost of $240 per complained material. It needs to be noted that supplier performance ratings and FLOP10 need to have similar methodology for calculating cost of poor supplier component quality. This particular change can be implemented in right away into supplier performance ratings and FLOP10 projects.

In addition, also the way in which cost of supplier on-time-delivery performance is calculated should be changed. Recommended equation for calculating costs related poor supplier on-time-delivery performance is alternative 2 that is provided in chapter 8.2.2. Proposed model is seen to more suitable for quality cost calculations because it examines actual costs. This particular equation has currently one drawback which is that loss of late delivery per purchase order line is estimated. In addition, it needs to be noted that current measurement method in FLOP10 differs greatly with the proposed model when the amount of POLs is less than 100. This is not an issue as results of new measurement scheme are evaluated against previously set targets. Hence, case company needs to calculate new baseline from 2011 figures with the new model before implementing it to action. However, further research about suitability of this measurement scheme is recommended before implementing it into any cost of quality calculations.

Measurement schemes need to drive performance improvement and behavioral change. Therefore this master's thesis indicates that results of measurements should be applied together with suppliers in order to decrease cost of non-conformance by finding the root causes of quality and on-time-delivery problems and seeking solutions to those. (Hughes et al.1998, p.184-185)

Pareto-analysis is recommended as an appropriate method for comparing different causes for poor quality and their related costs. According to Kanatsu.1990,p.25 Pareto diagrams and other charts make difficult material easy to understand. Quality will be improved only after these problems are fixed and this will lead to savings in terms of poor quality costs.

Systematic annual review should be carried out as it will ensure that the measurement regime remains valid and relevant. Therefore annual review of proposed measure schemes should be put in practice in the case company and models need to be amended if changes in environment suggest so. In addition, calculation of cost of poor supplier quality should be revised or completely terminated in case results are not applied in supply chain development as in that case resources are used ineffectually. (Hughes et al.1998, p.194-195)

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Appendix 1 – GATE Model

Gate 0 (G0) Scope Phase;

Confirm that an early review of the idea and purpose has been done and basic questions for the proposed project are addressed.

Gate 1 (G1) Requirements Phase;

Confirm that agreement is achieved on project scope, objectives, budget and timeline.

Gate 2 (G2) Planning Phase;

Confirm that the Business Opportunity Analysis and requirements are agreed upon and that the project is described in sufficient detail to proceed.

Gate 3A (G3A) Development Phase;

Confirm that there is agreement on process design and architecture. Confirm the business opportunity and that activity planning is done and all consequences on timing, cost and potential risk are analyzed.

Gate 3B (G3B) Development and Installation Phase;

Confirm the business opportunity and that activity planning is done and all consequences on timing, cost and potential risk are analyzed.

Gate 4 (G4) Validation Phase;

Confirm that the developed and tested solution is ready for piloting.

Gate 5 (G5) Implementation Phase;

Confirm that the solution is verified by the pilot test and that the plan for implementation.

Gate 6 (G6) Benefits Delivery Phase;

Confirm that implementation plan is completed and formally close the project and ensure that operational elements are in place.

Gate 7 (G7) Maintenance and Improvement;

Confirm that business case is on track by evaluating status of the implemented solution. Also confirm that lesson learned have been acted

Appendix 2 – Direct Costs

1.0	**PREVENTION COSTS**
1.1	Marketing/Customer/User
1.1.1	Marketing Research
1.1.2	Customer/User Perception Surveys/Clinics
1.1.3	Contract/Document Review
1.2	Product/Service/Design Development
1.2.1	Design Quality Progress Reviews
1.2.2	Design Support Activities
1.2.3	Product Design Qualification Test
1.2.4	Service Design—Qualification
1.2.5	Field Trials
1.3	Purchasing Prevention Costs
1.3.1	Supplier Reviews
1.3.2	Supplier Rating
1.3.3	Purchase Order Tech Data Reviews
1.3.4	Supplier Quality Planning
1.4	Operations (Manufacturing or Service) Prevention Costs
1.4.1	Operations Process Validation
1.4.2	Operations Quality Planning
1.4.2.1	Design and Development of Quality Measurement and Control Equipment
1.4.3	Operations Support Quality Planning
1.4.4	Operator Quality Education
1.4.5	Operator SPC/Process Control
1.5	Quality Administration
1.5.1	Administrative Salaries
1.5.2	Administrative Expenses
1.5.3	Quality Program Planning
1.5.4	Quality Performance Reporting
1.5.5	Quality Education
1.5.6	Quality Improvement
1.5.7	Quality System Audits
1.6	Other Prevention Costs

2.0	**APPRAISAL COSTS**
2.1	Purchasing Appraisal Costs
2.1.1	Receiving or Incoming Inspections and Tests
2.1.2	Measurement Equipment
2.1.3	Qualification of Supplier Product
2.1.4	Source Inspection and Control Programs
2.2	Operations (Manufacturing or Service) Appraisal Costs
2.2.1	Planned Operations Inspections, Tests, Audits
2.2.1.1	Checking Labor
2.2.1.2	Product or Service Quality Audits
2.2.1.3	Inspection and Test Materials
2.2.2	Set-Up Inspections and Tests
2.2.3	Special Tests (Manufacturing)
2.2.4	Process Control Measurements
2.2.5	Laboratory Support
2.2.6	Measurement (Inspection and Test) Equipment
2.2.6.1	Depreciation Allowances
2.2.6.2	Measurement Equipment Expenses
2.2.6.3	Maintenance and Calibration Labor
2.2.7	Outside Endorsements and Certifications
2.3	External Appraisal Costs
2.3.1	Field Performance Evaluation
2.3.2	Special Product Evaluations
2.3.3	Evaluation of Field Stock and Spare Parts
2.4	Review of Test and Inspection Data
2.5	Miscellaneous Quality Evaluations

3.0	**INTERNAL FAILURE COSTS**
3.1	Product/Service Design Failure Costs (Internal)
3.1.1	Design Corrective Action
3.1.2	Rework Due to Design Changes
3.1.3	Scrap Due to Design Changes
3.1.4	Production Liaison Costs
3.2	Purchasing Failure Costs
3.2.1	Purchased Material Reject Disposition Costs
3.2.2	Purchased Material Replacement Costs
3.2.3	Supplier Corrective Action
3.2.4	Rework of Supplier Rejects
3.2.5	Uncontrolled Material Losses
3.3	Operations (Product or Service) Failure Costs
3.3.1	Material Review and Corrective Action Costs
3.3.1.1	Disposition Costs
3.3.1.2	Troubleshooting or Failure Analysis Costs (Operations)
3.3.1.3	Investigation Support Costs
3.3.1.4	Operations Corrective Action
3.3.2	Operations Rework and Repair Costs
3.3.2.1	Rework
3.3.2.2	Repair
3.3.3	Reinspection/Retest Costs
3.3.4	Extra Operations
3.3.5	Scrap Costs (Operations)
3.3.6	Downgraded End-Product or Service
3.3.7	Internal Failure Labor Losses
3.4	Other Internal Failure Costs

4.0	**EXTERNAL FAILURE COSTS**
4.1	Complaint Investigations/Customer or User Service
4.2	Returned Goods
4.3	Retrofit Costs
4.3.1	Recall Costs
4.4	Warranty Claims
4.5	Liability Costs
4.6	Penalties
4.7	Customer/User Goodwill
4.8	Lost Sales
4.9	Other External Failure Costs

Appendix 3 – Case company's COPQ categories

Process COPQ 1 Sales
- COPQ 1.1 Cost difference at handover
- COPQ 1.1.1 Cost difference at handover

Process COPQ 2 Engineering
- COPQ 2.1 Engineering negative variances
- COPQ 2.1.0 Engineering negative variances
- COPQ 2.1.1 Cost overrun on customer orders
- COPQ 2.1.2 Cost overrun on R&D projects
- COPQ 2.1.3 Engineering / design rework

Process COPQ 3 Manufacturing / Production
- COPQ 3.1 Manufacturing negative variances
- COPQ 3.1.0 Manufacturing negative variances
- COPQ 3.1.1 Rework
- COPQ 3.1.2 Scrap
- COPQ 3.1.3 Unplanned cost due to machine breakdown
- COPQ 3.2 Excess / obsolete inventory
- COPQ 3.2.1 Excess / obsolete inventory

Process COPQ 4 SCM
- COPQ 4.1 Project materials negative variances
- COPQ 4.1.1 Project materials negative variances
- COPQ 4.2 Supplier non performance (internal & external)
- COPQ 4.2.0 Supplier non performance (internal & external)
- COPQ 4.2.1 Quality
- COPQ 4.2.2 OTD
- COPQ 4.2.3 Quality internal
- COPQ 4.2.4 OTD internal
- COPQ 4.3 Transportation excess cost
- COPQ 4.3.0 Transportation excess cost
- COPQ 4.3.1 Premium freight & Overrun: Inbound
- COPQ 4.3.2 Premium freight & Overrun: Outbound
- COPQ 4.3.3 Uncovered damages and excesses

Process COPQ 5 Site work
- COPQ 5.1 Site Works negative variances
- COPQ 5.1.0 Site Works negative variances
- COPQ 5.1.1 Cost overrun in Civil works
- COPQ 5.1.2 Cost overrun in Erection
- COPQ 5.1.3 Cost overrun in Commissioning

Process COPQ 6 Project Management
- COPQ 6.1 Managing projects - negative variances
- COPQ 6.1.1 Managing projects - negative variances
- COPQ 6.2 Customer concessions
- COPQ 6.2.0 Customer concessions
- COPQ 6.2.1 Concessions
- COPQ 6.2.2 Credit memos
- COPQ 6.2.3 Penalties
- COPQ 6.2.4 Liquidated Damages
- COPQ 6.3 Contingencies and provisions utilized
- COPQ 6.3.1 Contingencies and provisions utilized

Process COPQ 7 Support Processes
- COPQ 7.1 Infrastructure failures cost
- COPQ 7.1.1 Infrastructure failures cost
- COPQ 7.2 OHS additional cost
- COPQ 7.2.1 OHS additional cost
- COPQ 7.3 Non-compliance cost
- COPQ 7.3.0 Non-compliance cost
- COPQ 7.3.1 Legal fees
- COPQ 7.3.2 Fines
- COPQ 7.3.3 Internal SOX or Audit deficiences
- COPQ 7.4 Account receivables past due
- COPQ 7.4.1 Account receivables past due
- COPQ 7.5 Underabsorption
- COPQ 7.5.0 Underabsorption
- COPQ 7.5.1 People
- COPQ 7.5.2 Expenses

Process COPQ 8 Aftersales
- COPQ 8.1 Warranty
- COPQ 8.1.1 Warranty
- COPQ 8.2 Resolving customer issues
- COPQ 8.2.0 Resolving customer issues
- COPQ 8.2.1 Customer complaints
- COPQ 8.2.2 Product recalls
- COPQ 8.3 Cost to remedy Software errors
- COPQ 8.3.1 Cost to remedy Software errors