NTNU 97005

CUSTOMER AND PROCESS FOCUSED POOR QUALITY COST MODEL USED AS A STRATEGIC DECISION-MAKING TOOL

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Dr. Ing. Thesis/Ph.D. Dissertation

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PREFACE

This dissertation is a result of my Ph.D. work partly done at the Norwegian University of Science and Technology, Department of Production and Quality Engineering, and partly at Rochester Institute of Technology, The John D. Hromi Center for Quality and Applied Statistics.

The results of my work are presented in eight chapters:

1. A brief historic overview of the development of quality cost measurement.
2. A review of existing publications on quality cost measurement and its application, where shortcomings and limitations in previous approaches have been used to define the rationale and purpose of the research.
3. A new customer and process focused poor quality cost model is proposed where each element of the model and necessary premises are described.
4. A description of the alignment of each element in the model through the use of Quality Function Deployment (QFD). QFD is one of two main techniques used in the new poor quality cost model.
5. A description of how Taguchi's loss function has been derived and used to monitor poor quality costs. Taguchi's loss function is the other main technique utilized in the model.
6. A description of a case study accomplished at Eastman Kodak Company in Rochester, New York. Data from Kodak have been used to test and verify the model.
7. A brief summary of the work.
8. A short juxtaposition of thoughts about how the model may be implemented, and recommendations for further research within the field of poor quality cost measurement.

I would like to thank a number of people who have made my work possible. Professor Asbjørn Aune, at the Norwegian University of Science and Technology, Department of Production and Quality Engineering, has been supervising my efforts, allowing me to set the directions of my research and supporting my choices. I would never have been able to start this work if it had not been for former colleagues at Elkem Aluminium Mosjøen, and especially Sigmund Brekke. They helped me initiate and finance the first part of my study. This support was later undertaken by my present employer, the Norwegian Institute of Wood Technology. My deepest thanks to Magnar Müller and Jostein Byhre Baardsen for their support.

A number of people at Eastman Kodak Company and Strong Memorial Hospital have been an invaluable help in gathering necessary data. I would especially like to emphasize the undivided support I received from Barbara Pociatek, Robert Meisel, and Joe Orlando.

Finally, I would like to express my sincere thanks to everyone who helped me at the John D. Hromi Center for Quality and Applied Statistics. Dr. John Hromi and Dr. Don Baker for inviting me to the US and helping me in any way possible. Dr. John Burr, Tom Barker, and Dr. Edward Shilling for listening to my problems and giving me directions. Dr. Dan Lawrence for helping me with correspondence analysis, and Dr. Joe Voelkel for his help in integrating the loss function.

Oslo, April 15, 1997
Rune M. Moen

To My Late Father

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ABSTRACT

The first part of the dissertation (Chapter 1 and 2) contains a review and evaluation of the previous use of quality cost measurement, which serves as a foundation for the research rationale and purpose. The second part (Chapter 3, 4, and 5) describes a new customer and process focused poor quality cost (PQC) model. Part three (Chapter 6, 7, and 8) deals with the testing and verification of the model through a case study, together with some thoughts about the implementation and further development of the model.

The concept of quality cost measurement emerged in the mid 1950s as a mean to convince top management that they had to focus on statistical tools for quality control. Statistical Quality Control Departments were no longer able to convince managers solely based on enthusiasm for the statistical tools, and felt the need to communicate in the language of management. Since the concept first emerged, several new models and cost elements have been proposed. However, most of them are mainly adjustments of the original thoughts, and the use of quality cost measurement is advocated relatively similar today as it was in the 1950s. In the same period of time, production has changed considerably. Efficient production in the 50s was based on mass production of standardized products in a seller's market, where customers more or less had to accept whatever the manufacturer offered. Today's production is characterized by mass customization in a very competitive market, where customers demand to have their requirements fulfilled. It is a buyer's market with too many providers of products and services compared to the demand. The quality cost concept has not kept up with the extensive changes we have seen in manufacturing, which gives the research rationale.

The purpose of the research has been to develop a customer and process focused poor quality cost model usable as a strategic decision-making tool for top management. The most important input to the model is customer requirements, needs, and expectations. Process parameters that have an influence on the fulfillment of customer requirements have been measured through the Taguchi loss function, while Quality Function Deployment (QFD) has been used to translate customer requirements to process parameters. The new model enables a company to link customer requirements directly to process parameters that influence these requirements (denoted *key process parameters*), and to focus the improvement effort to yield maximum benefit for the customer.

The QFD matrix has been used to translate customer requirements to key process parameters and to determine the importance and performance of each customer requirement and key process parameter. Correspondence analysis has been used to improve the accuracy of the calculated importance of each customer requirement. The matrix has also been used to estimate intangible poor quality costs, and as a tool to prioritize elements for further analysis.

Variation in how customer requirements are met and performance variations in key process parameters have been measured by the Taguchi loss function. Stepwise quadratic loss functions have been derived for critical internal and external failure costs, customer incurred costs, and environmental costs. Critical failure costs are costs that occur due to failures that directly influence the fulfillment of customer requirements. Each loss function has been linked to actual process performance to calculate an expected loss for each

customer requirement. Critical internal failure costs have been measured based on the variation in performance of each key process parameter, and a methodology for transforming these costs back to customer requirements has been described. Critical external failure costs, customer incurred costs, and environmental costs have been measured directly based on how the manufacturer meets customer requirements. A methodology for gathering necessary process information for the loss function has been developed, and a simplified Activity Based Costing (ABC) approach used to distribute cost to each activity based on their resource consumption. Costs have been tied to the loss function through cost drivers, like number of failures per month.

A case study based on an X-ray film processor was accomplished at Eastman Kodak Company to test and verify the new model. A focus group consisting of users from different functions of a large hospital, and representatives from a dealer of X-ray equipment, identified customer requirements. The importance and how each customer requirement was met compared to expectations was determined through a survey accomplished at the hospital and the dealer. How each requirement was met compared to the chief competitor was also determined through the survey. Data were analyzed through correspondence analysis to form user groups, that was given different weights regarding their influence on the purchase and re-purchase decision of the product. Analysis of variance showed that this was a more appropriate way of grouping data than by customer groups, which is the traditional approach in QFD. The most important customer requirement was chosen for further analysis.

A cross functional team at Kodak identified key process parameters that influenced the fulfillment of the chosen customer requirement. They also made qualified guesses about the manufacturing tolerances that should be used to satisfy the customer. Loss functions were constructed for each cost category based on information from the hospital and Kodak, and linked to actual process performance that was determined based on customer complaint records and reports of manufacturing problems. Intangible costs were estimated based on the QFD matrix and valuations of financial consequences of loosing the customer due to poor fulfillment of customer requirements.

The implementation of the new model is beyond the scope of this project, but some suggestions based on experience from the case study have been included, along with suggestions for further research.

INTRODUCTION

Measuring quality costs have been emphasized as an important part of quality improvement since the early 1950s. A chapter on quality costs seems almost compulsory in every book pertaining to Total Quality Management, Business Process Improvement, Process Re-engineering, and similar topics. There is no doubt that measuring quality costs is useful in order to direct improvement efforts, the problem is that the concept has lost some of its validity. While customer requirements and production systems have changed considerably during the last decades, quality cost measurement is advocated nearly the same way as it was forty years ago.

To me, the need for a new approach arose as a result of my work at Elkem Aluminium Mosjøen, and later the Norwegian Institute of Wood Technology, where I was working with quality improvement based on quality cost measurement. Difficulties regarding how to measure and document the effects of quality improvement activities were experienced as obstacles to continuous improvement. Top management were not willing to give their long time support, since they were unable to see the effect in their financial reports. It was also difficult to reveal the effect that improvements had on customer satisfaction and loyalty. Companies with an operational quality assurance system seemed able to prevent failures from leaving the production plant. Improvements usually embraced only internal processes in a company that lead to reduced operating costs. The quality of shipped products was not improved to the same degree. I felt that a new approach was required, a model that enables the provider of a product or service to focus on elements that really matters to their customers.

Customer needs are not adequately addressed because the current paradigm in many organizations is that marketing and sales groups have separate agendas, performance goals, vocabularies, and work processes than the product development and engineering group. They are out of touch with each other's business process. Marketing people have frequent contact with the customer, while engineering people are more technology driven. Barriers between different parts of an organization have to be eliminated.

The objective of my work was to develop a new customer and process focused poor quality cost (PQC) model that enables a manufacturer to direct his improvement efforts to yield maximum benefit for his customers, based on his customers' requirements, needs, and expectations. The model emphasizes the importance of linking interdependent activities in the company to the customer, to enable cross functional cost measures that can be utilized by top management in their strategic decision-making process.

The main input to the model is customer requirements, needs, and expectations, and the output Taguchi's loss function used to monitor poor quality costs. Quality Function Deployment (QFD) has been used to translate the voice of the customer to process parameters. The QFD matrix is also used to estimate intangible costs. Traditional cost categories have been altered, and the expected loss for each cost category has been estimated based on actual process performance and stepwise quadratic loss functions with multiple intervals. The intended use of the model is as a strategic decision-making tool that is able to link long term quality improvement to customer satisfaction and loyalty.

The dissertation contains a comprehensive review of publications within the field of quality cost measurement, and an evaluation of existing quality cost models. Shortcomings that were revealed and evaluated through this review gave the rationale and purpose of the research. The new customer and process focused poor quality cost model was developed to overcome some of the identified problems, and later tested and verified through a case study at Eastman Kodak Company in Rochester, New York. The model is based on a wide use of existing tools and techniques that should be present in a company that wishes to be a world class manufacturer.

The main element of novelty value is the overall system approach to poor quality cost measurement, and how existing information can be used to give a more accurate picture of the company's poor quality costs. Costs have been measured across functional boundaries, and they are directly linked to customer satisfaction and loyalty.

Another element of novelty value is the use of correspondence analysis to improve customer surveys and the input to the QFD matrix. The objective was to obtain as accurate information as possible regarding the customer's evaluation of importance for each customer requirement. User groups within customer groups were identified and weighed based on their influence on the purchase or re-purchase decision of a product or service.

A third element of novelty value is the process approach to Taguchi's loss function. Stepwise quadratic loss functions with multiple intervals have been linked to actual process performance, and a methodology of gathering necessary cost and performance data has been provided. The calculation of actual losses has been partly computerized with the possibility of simulating how shifts in performance will influence the loss. The loss function links customer requirements to process steps (key process parameters) that influence how customer requirements are met.

The last element of novelty value deals with how to estimate intangible poor quality costs. These costs have been described as crucial for the company, but unknown and unknowable. Intangible costs have been linked to how each customer requirement was met by the manufacturer through the QFD matrix, as well as a break-down of costs to a manageable level where it is possible to make reliable estimates.

The implementation of the model, along with the verification of some elements, is beyond the scope of this work. A comprehensive and long term commitment from a manufacturing company would have been required.

1. DEVELOPMENT OF QUALITY COST MEASUREMENT

1.1 QUALITY COST MEASUREMENTS FROM ITS ORIGIN

The quality cost concept is not of recent date but has been developed during the last 45 years. The first development took place among quality control professionals of industrial engineering. One of the first writings pertaining to the general concept of quality cost can be found in Dr. J. M. Juran's first Quality Control Handbook, published in 1951, with his now famous analogy "gold in the mine" (ASQC Quality Cost Committee, 1990). The interest for quality costs arose because the Statistical Quality Control Departments found that they could no longer "sell" their programs solely on enthusiasm for the statistical tools. The solution was a new approach based on the language of management, that was money (Juran, 1974). Armand V. Feigenbaum (1956) classified quality costs into today's familiar categories of prevention, appraisal and failure. Feigenbaum's classification has since been almost universally accepted (Plunkett and Dale, 1987), and his theory has been instrumental in focusing the attention of management on quality as an important business parameter (IAQ, 1995).

The next main development came in 1963 when the US Department of Defense issued MIL-Q-9858A "Quality Program Requirements," making identifying costs related to quality a requirement on many government contracts and subcontracts. These requirements were further specified in MIL-STD-1520B (original issue MIL-STD-1520) released in May 1974, listing actual costs that had to be collected and summarized (Campanella and Corcoran, 1983). Amendment 2 of MIL-Q-9858A dated March 1985 even requires the contractors, upon request, to furnish the quality cost data to the government. Another widely used industry standard describing quality cost systems is the British Standard BS 6143 (Guide to the Economics of Quality, 1990-92). This standard deals with quality costs in two parts, one describing the principles of total quality management, and the other describing the prevention, appraisal and failure concept.

The third and latest development within quality costing started in the mid 1980s driven by the accounting literature, and can be found in periodicals like *Journal of Cost Management, Management Accounting, Journal of Business Strategy, Accounting Horizons, Management Accounting Research, etc.* New accounting techniques have been introduced as a supplement to the traditional quality cost measurement. One of the most important contributions is the use of Activity Based Costing (ABC) to monitor overhead costs and to give a better understanding of where recourses are consumed within a company (Shepherd, 1995; Cooper et. al., 1992; Brimson, 1991; Beheiry, 1991). The accounting literature has also put focus on shortcomings in traditional accounting systems regarding their ability to focus on poor quality and measure the effect of quality improvement (Reynolds, 1989; Kaplan, 1988). Intangible quality costs like customer dissatisfaction and lost sales because products are defective have been proposed measured with Taguchi's loss function[1] (Kim and Liao, 1994; Albright and Roth, 1992; Fink, Margavio, and Margavio, 1994).

[1] Genichi Taguchi is a Japanese engineer who has developed several statistical methods for off- and online quality control. One of his contributions is the loss-function describing quality costs as a quadratic loss to society when product characteristics deviate from the target value. The function give ways to measure intangible quality costs like customer dissatisfaction and lost sales because products are defective.

Since the early 60s a main driving force has been the American Society for Quality Control's (ASQC) Quality Cost Committee. The objective of this committee was, and is, to "dramatize the magnitude and importance of product quality to the well-being of a manufacturing business through measurements of the cost of quality" (ASQC Quality Cost Committee, 1990). In 1967 the committee published *Quality Costs - What and How* to detail what should be contained in a quality cost program, and to provide definitions for categories and elements of quality costs. This book became the largest seller of any ASQC publication until its successor *Principles of Quality Costs* was published in 1986. This book was the first ASQC publication to surpass 10,000 copies sold. The second edition of this book was published in 1990, and the third edition is expected in 1997. The ASQC Quality Cost Committee has become a recognized authority for the promotion and use of quality cost systems. They are responsible for numerous conventions and publications within the field (ASQC Quality Cost Committee, 1977; 1984; 1987; 1989), including two collections of articles and papers related to the quality cost concept, and improvement, published between 1970 and 1982 (1984) and between 1983 and 1987 (1989). Another source of quality cost literature is *Quality Progress*, a monthly publication of ASQC. A special issue in April 1983 was devoted exclusively to quality costs to emphasize the importance of the topic.

1.2 MODELS USED TO MONITOR QUALITY COSTS

Since the quality cost concept was first introduced, several different models and approaches have been proposed. The three basic cost categories were originally defined as (Feigenbaum, 1956):

- ***Failure costs** are caused by defective materials and products that do not meet company quality specifications. They include such loss elements as scrap, spoilage, rework, field complaint, etc.*
- ***Appraisal costs** include the expenses for maintaining company quality levels by means of formal evaluations of product quality. This involves such cost elements as inspection, test, quality audits, laboratory acceptance examinations, and outside endorsements.*
- ***Prevention costs** are for the purpose of keeping defects from occurring in the first place. Included here are such costs as quality control engineering, employee quality training, and the quality maintenance of patterns and tools.*

Failure costs have since been divided into internal and external failure costs. Internal failure costs are caused by any error, mistake, defect, and fault that is discovered prior to shipment of a product or the delivery of a service. External failure costs accumulate when failures are discovered after shipment. The external category may include elements such as warranty claims, cost of processing customer complaints, lawsuits, product recalls, etc.

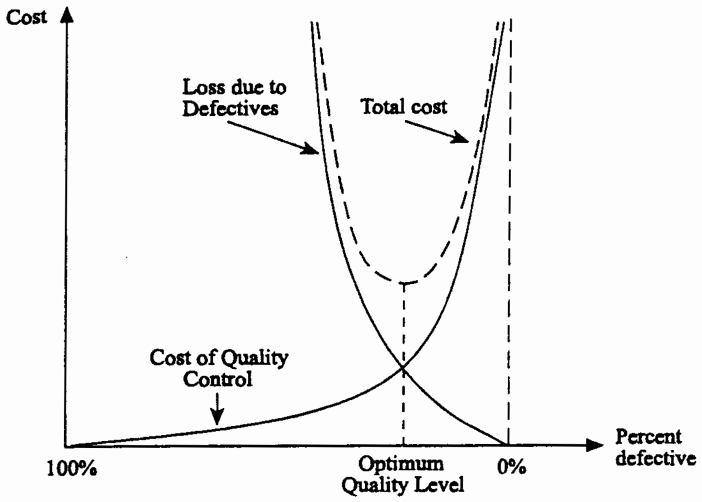


Figure 1.1 Classic Model for Quality Cost Element Interaction (Juran, 1951)

The first model that described the relationship between the cost of quality control and loss due to defectives (Figure 1.1) was presented by Juran in his first Quality Control Handbook (Juran, 1951). The model showed that a decrease in loss due to defectives resulted in an asymptotic increase in cost of quality control. Cost of quality control was later divided into costs of prevention and appraisal. According to the original quality cost theory, prevention and appraisal costs increased as the product quality increased (number of failures decreased), while failure costs decreased. The result was an overall quality cost curve that was U-shaped, with an Optimum Quality Level that every company should strive to reach (Figure 1.1). The model implied that this level was less than 100 percent conformance. This was an internal company focused model that did not include costs due to lost customer goodwill and other lost opportunity costs that occur because an organization produces poor quality products. Another problem with this model was that failure costs are driven by defect rates. These defect rates are defined as products with some characteristic that when measured, fall outside specification limits (Albright and Roth, 1992). All units within the specification limits are considered to be equal, regardless of whether they fall at the target value or near the specification limits. This is not in line with the Total Quality Management (TQM) philosophy where the key focus is on the needs and requirements of the customer, process understanding, and continuous process improvement measured as reduced process variability. The model does not consider costs due to low process efficiency, and does not support the assumption that there are hidden costs associated with variability when product characteristics deviate from the target value.

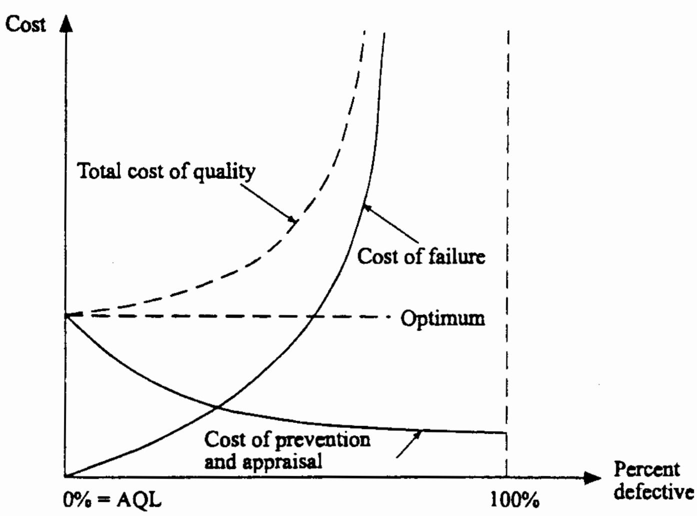


Figure 1.2 New Model for Quality Cost Element Interaction (Schneiderman, 1986)

The first model was applicable when it was advocated, serving as a selling point for statistical quality control. The companies were operating in a seller's market, and their production was based on human labor and control of finished products. As customer requirements increased and the market demanded higher product quality (less failures), it became increasingly evident that the only acceptable standard for process performance was zero defect (Pall, 1987). Control of finished products became too expensive, and manufacturers had to convert to process control to obtain the required quality level. Figure 1.2 (Schneiderman, 1986) shows a new model where it is assumed that a direct attack on failure costs, with a modest increase in prevention and appraisal costs, will lower the total cost of quality and thus increase profit. Appraisal costs are then reduced according to results achieved, while prevention efforts are redirected to gain further improvement. The cost of failure will decrease steadily as the point of zero defects is approached, while prevention and appraisal costs reach an optimum level where the cost of quality is lowest (at the point of zero defects). This strategy is based on the premise that for each failure there is a *root cause*, causes are *preventable*, and prevention is always *cheaper* than correction (ASQC Quality Cost Committee, 1990).

Numerous studies have addressed the use of quality costs and the cost distribution among the different cost categories (Table 1.1).

Table 1.1 Distribution of Quality Costs (Abed and Dale, 1987)

Authors	Industry/ Company	Quality cost categories expressed as percentage of total quality cost			Total quality cost as a % of sales	Comments
		Prevention	Appraisal	Failure		
Masser	General Electric	7.7	23.8	68.5	7.8	Actual figures.
Feigenbaum	General industry	5	25	70	10	Typical figures.
Nixon	In total across all industries	5	25	70	10	Estimated percentage of GNP.
Dunn	Different industries	5	25	70	5-20	Typical figures.
Juran and Gryna	Different industries	1-5	10-50	25-45	0.5-2.5	Different figures for each industry.
Brown	Standard telephone and cables	2.7	31.5	65.8	8.4	Actual figures.
Burns	Machine tools	3.3	40.3	56.4	5	Actual figures.
Norton	General industry	5	25	70	4-14	Typical figures.
Blank and Solorzarno	Electronics	8	25	67	2	Actual figures
Anon	Range of industries	10	26	64	5.8	Average of range of industries.
Urwick Orr and Partners	Range of industries	2.5	10	87.5	10-25	Average of range of industries.

This summary shows that the failure category represents between 25% and 87.5% of the total quality cost. A common denominator for most of these studies is that the failure cost element is not only the largest, but also the main reason for the whole concept (Juran, 1988). Juran stated that internal and external failure costs account for between 50 and 80% of the total cost of quality. The total cost of quality is strongly dependent on product complexity, state of the technology used, how the customer uses the product, the elements of quality cost that are included, and the level of refinement of the quality system within the company (Harrington, 1987). Reported quality costs in manufacturing companies typically range from 5% to 40% of revenue, where the lower number probably reflects insufficient recording of actual costs. The situation in service companies is not better. It is estimated that 30% to 50% of service companies' operating expenses are spent on quality costs, with about 70% of that allocated to failure costs (Gray, 1995). The number and type of elements that are included in various quality cost systems differs strongly from company to company, which makes it difficult to compare quality cost data. Comparisons like the one in Table 1.1 have to be considered guidelines, not established truths, due to the uncertainty of which cost elements that have been included in the cost analysis.

Several other quality cost elements have been proposed in addition to Feigenbaum's original elements (prevention, appraisal, and failure), bringing the quality cost concept more in line with the TQM philosophy. Feigenbaum (1983) described the following elements (indirect quality costs and equipment quality costs were also described in Feigenbaum's first edition of *Total Quality Control* that was published in 1961, and Juran described intangible costs in his first *Quality Control Handbook* from 1951);

Indirect Quality Costs and Vendor Quality Costs
Indirect quality costs represent those quality costs that are hidden in other business costs as unnecessary manufacturing operations made standard for reasons of uncertain quality, and unnecessary design features introduced because of weak control of quality of design. Vendor quality costs are indirect costs as a result of the supplier's quality costs that are included in the purchase price.

Intangible Quality Costs and "Liability Exposure" Costs
Intangible quality costs are those costs associated with the loss of customers' goodwill as a result of unsatisfactory quality as perceived by customers, which leads to future lost sales. Liability exposure is both direct costs associated with lawsuits and lost goodwill due to the result of the lawsuit.

Equipment Quality Costs
Equipment quality costs represent the capital investment in equipment specifically obtained to measure product quality for purposes of acceptance and control, together with the related equipment amortization, the buildings, and occupied floor space.

Life Cycle and User-Oriented Quality Costs
These are costs associated with maintaining the product quality over a reasonable period of product use, including such costs as those for service, repairs, replacement parts, and similar expenditures. This element includes both preventive and corrective activities. Since Feigenbaum's definition, recycling costs have also become an important part of life cycle costs.

Harrington (1987) has proposed a cost structure (Figure 1.3) with many of the same elements as described by Feigenbaum. The model has two major cost categories, direct and indirect poor quality costs (PQC). The direct PQC category includes controllable PQC that is prevention and appraisal, resultant PQC divided into internal and external error costs, and equipment PQC. The equipment PQC category includes all investment in equipment used to perform the activities associated with controllable and resultant PQCs. The controllable category includes elements that management can control directly, while the resultant categories are related to management decisions made in the controllable category.

The other main category, indirect PQC, deal with a company's ability to fulfill their customers' expectations. Customer incurred costs appear when the product or service fails to meet the customer's expectations completely, and the customer suffers direct economic loss due to this insufficiency. This element may include disturbances in the customer's production processes, time used to return defective merchandise, overtime to make up production, etc. Life Cycle and User-Oriented Quality Costs as described above are included in this element. The other two elements in the indirect category are customer dissatisfaction costs that occur when the customer restrains from re-purchasing the product, and loss-of-reputation costs that reflect the

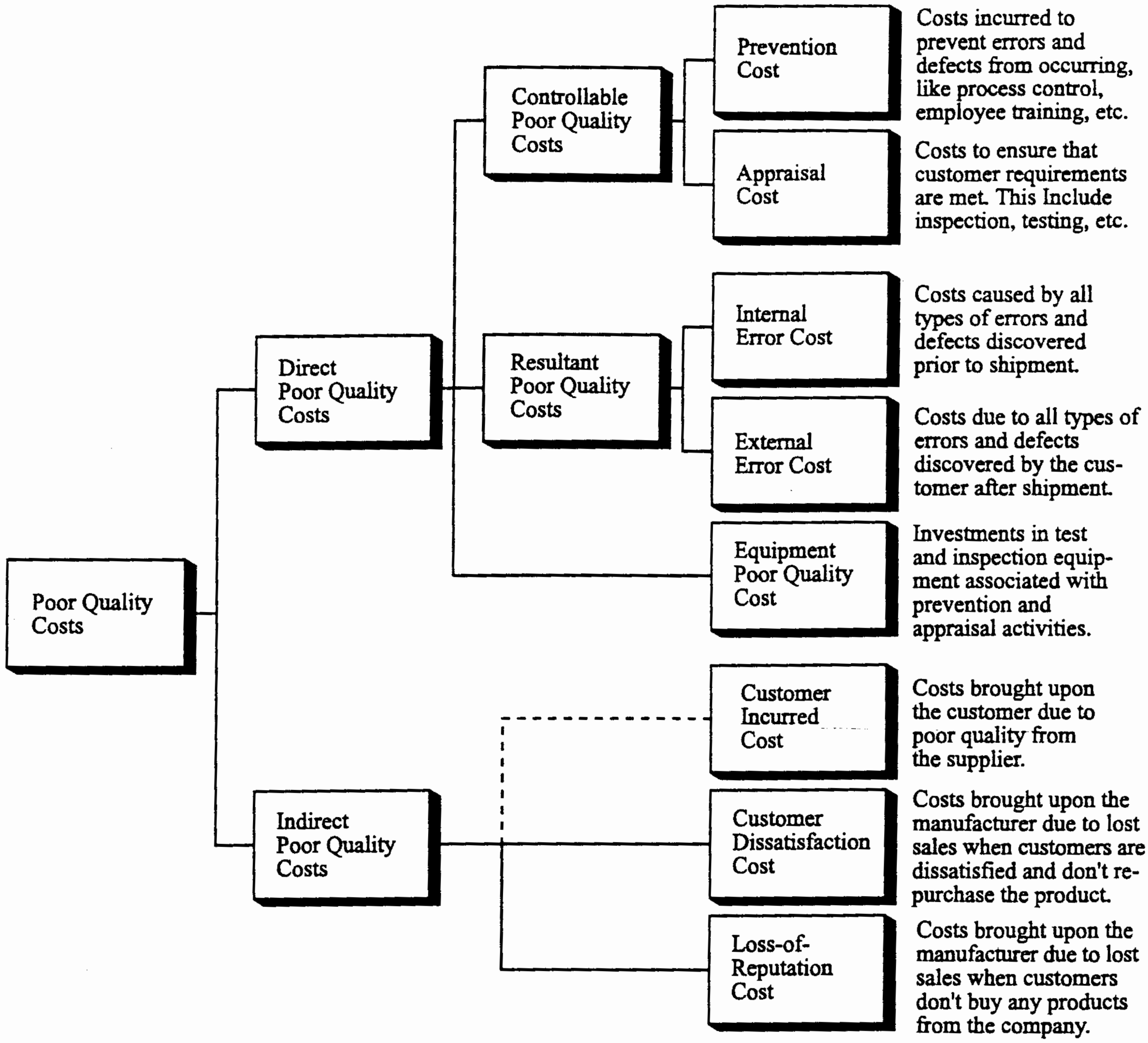


Figure 1.3 Poor Quality Cost Model (based on Harrington, 1987)

customer's attitude towards the company rather than towards an individual product. The two latter elements accrue at the manufacturer as a direct result of customer incurred costs and direct poor quality costs (external error costs). Intangible Quality Costs and "Liability Exposure" Costs are included in these two elements.

In recent years, the customer expectation level has increased along with the customers' consciousness about the quality of products and services, making the knowledge and control of the indirect cost category increasingly important to the company. Another reason for focusing on indirect quality costs is the changes we see in our society. Information is becoming an increasingly important part of our lives, and production as we know it is becoming obsolescent. The production society we know with gigantic corporations focusing on mass production of standardized products is being replaced by smaller units that are more responsive to customers and their needs. The new trend is mass customization where products are adapted to individual customer's requirements. This can be illustrated by Levi Strauss & Co. in USA who fits their standardized jeans models to the individual customer. Each measure is transmitted to the factory who produces and ships the finished product to each customer. Toffler (1990) describes the information age as a time driven by requirements, needs and assessments compared to the industrial age that was driven by production, costs, quotas and financial indicators. The new society is driven by customers rather than products, and a cost system enabling the company to understand customers and their needs will be increasingly important.

The draft of the new ISO 10014 standard, *Guidelines for managing the economics of quality (1996)*, identifies four major approaches to the classification of quality costs:

- A model where costs are grouped under the headings "Prevention, Appraisal and Failure" (PFA Model).
- A model where costs are grouped under the headings of cost of conformity and cost of non-conformity (Process Model).
- A model where the costs are grouped under the different phases of the life cycle of the product (Life-Cycle Model).
- A model that focuses on identifying and measuring added value and costs that accumulate as a result of resolving badly designed or performed activities.

The PFA model was described by Feigenbaum in 1956, and is still considered the most generally useful as an aid for decision-making (Musgrove and Fox, 1991). The Process Model breaks down all the activities of the company into interlinked processes, and divides costs into costs of conformance (COC) and costs of non-conformance (CONC), based on the output of each process (Elsen and Fellowell, 1993; Musgrove and Fox, 1991). British Standard BS 6143 Part 1 (1991) defines the cost of conformance as being intrinsic in providing products and services in a 100% effective manner. The cost of non-conformance includes all types of waste beyond the 100% effective manner, that is, inefficiencies within the specified process that are seen as unnecessary costs. Costs of conformance can also be viewed as costs accrued to ensure that the product is produced according to specifications (prevention and appraisal costs), and costs of non-conformance as costs incurred when specifications are not met (failure costs and indirect costs).

1.3 THE SCOPE OF A QUALITY COST SYSTEM

Leading authors have identified the following main objectives leading companies to go into programs of evaluating quality costs (Juran, 1988; Harrington 1987; Feigenbaum 1983; Dale 1994):

- Quantify the size of the quality problem in language that will have impact on upper management. The language of upper management is money, and quality costs bring quality out of the abstract and make it a reality able to compete with cost and schedule.
- Identify major opportunities for improvement and cost reduction in order to provide a better return on the problem solving effort. Quality costs are a result of specific problems with specific causes, where a relative few problems usually account for the bulk of the costs.
- Provide a means to measure the impact of corrective action and changes made to improve the process.
- Provide a simple, understandable method of measuring the effect poor quality has on the company, and provide an effective way to measure the impact of the quality improvement process.

- Establish bases for budgets to exercise budgetary control over the entire quality operation. Financial control is often based on the departmental organization with the result that the cost of inspection and testing have been included, since these costs are incurred by specific departments. Scrap, rework and field failures cut across departmental lines and have been excluded from traditional financial control.
- Change the way employees think about errors. They are able to understand the consequences of the errors they make, in terms they are familiar with (money).

The utilization of quality cost data has been numerous, and according to Morse (1983), "The potential use of the information contained in such a report [quality cost] are limited only by imagination of management." However, based on the reviewed literature, I find it appropriate to group the uses into two main categories:

1. Strategic, where quality cost data are used to promote product and service quality as a business parameter and convince upper management that they have to start a quality improvement process. This persuasive use of quality cost data was the basis of the quality cost philosophy when it was first introduced in the 1950s.
2. Operational, where quality costs give rise to performance measures that enable the company to measure, plan, and control their quality improvement efforts. This use includes, among other activities, trend analysis to display changes in costs over time, Pareto-analysis to identify quality improvement projects, identification of investment opportunities and performance indicators, and quality efficiency indexes.

The core purpose of every quality cost system should be to facilitate quality improvement efforts that will lead to operating cost reduction opportunities, increased customer satisfaction and loyalty, and thereby increased profit.

1.4 SEMANTIC CONSIDERATIONS AND DEFINITIONS

Since Juran introduced the term "The Economics of Quality" and contained discussions of the "Cost of Quality" in his first Quality Control Handbook (Juran, 1951), several terms have evolved covering approximately the same content. In traditional US and European quality literature "Cost of Quality" normally refers to the cost of assuring conformance and of managing and correcting non-conforming material (internal company costs associated with prevention, appraisal, failure, and external costs due to customer problems) (Sullivan, 1986). This definition is based on the Total Quality Control (TQC) concept from the 1960s and 70s, that generally refers to the quality of product and service, with a definition of quality as "conformance to requirements."

In the Japanese Company Wide Quality Control (CWQC) approach, which was more comprehensive than western TQC, cost was defined as "the loss to society which is determined by design cost, efficiencies in manufacturing, assembly, sales, service, customer ownership, and the contribution to society." CWQC refers to the quality of management, the quality of human behavior, the quality of work being done, quality of work environment, the quality of product, and the quality of service (Sullivan, 1986). Taguchi has defined quality as "The financial loss to society after the article is shipped." Since quality is normally perceived as conformance to a positive attribute, Taguchi's definition can be rewritten as "Quality is the avoidance of financial loss to society after the article is shipped." This definition relates quality to a monetary loss and not to a gut feeling or other emotional conditions (Barker, 1990). Whether the term "after the article is shipped" should be included in the definition or not has been questioned (Kackar, 1986). The idea of minimizing loss to society is rather abstract and thus difficult to deal with as a company objective. To make the definition more manageable the loss to society can be considered to be the long term loss to the company as a result of poor quality (ASQC Quality Cost Committee, 1990).

Different terms as "Quality Cost", "Total Quality Cost", and "Cost of Quality" may lead to an impression that it is more costly to produce quality items or perform every activity correct the first time. One of the key points emerging from the National Conference for Quality (Binstock, 1982) was the idea that the phrase "Cost of Quality" should never be used since quality is profitable, not costly. Harrington (1987) introduced the term "Poor Quality Cost" to stress the changes that have occurred in the way of thinking since the 1950s, and that quality does not lead to additional costs. Generally, quality costs (and equivalent terms) are used to describe all four cost categories, prevention, appraisal, internal and external failure cost. The term poor quality cost is usually reserved for the internal and external failure cost categories, based on the assumption that cost of absence of quality is usually considerably larger than the total of appraisal and prevention. The term "Quality Economics" has been proposed as a possible neutral compromise (IAQ, 1995), which leads back to the original term "The Economics of Quality" (Juran, 1951).

This text will use the term quality cost for the original concept of prevention, appraisal, internal and external failure costs. The term poor quality cost (PQC) will be used to describe the new customer and process focused poor quality cost model, embracing the cost of poor product, process, and service quality throughout the entire value adding chain, costs of not satisfying customers, and costs due to inadequate process efficiency (loss). The purpose is to evolve from the "zero-defect" approach based on specification limits to a process approach based on Taguchi's theories where every deviation from the target value inflicts a loss. *Prevention and appraisal costs are excluded from this definition of PQCs.* This text uses the interpretation of quality as "The avoidance of financial loss to society", where the loss to society has been considered the long term loss to the company as a result of poor quality. Every activity within the company has been embraced in the interpretation, since losses during manufacturing, like raw material, energy, and labor consumed to produce unusable products are considered societal losses.

The European Organization of Quality Control (EOQC) has defined failure as "The termination of the ability of an item to perform a required function" (EOQC, 1989). In this text, and in traditional quality cost literature, the term failure embraces far more than the content of this definition. Failure costs include all direct financial consequences of every error, defect, mistake, fault and failure that arise anywhere in the company.

Additional definitions of terms used in this text can be found in Appendix H.

2. REVIEW AND ARGUMENTATION ON THE USE OF POOR QUALITY COST MEASUREMENTS IN THE IMPROVEMENT PROCESS

The objective of this chapter is to state the rationale and purpose of my research. A large number of existing publications on quality improvement and quality cost measurement has been reviewed, and are presented along with personal experience from quality improvement projects in Norway.

2.1 ARGUMENTATION ON THE USE OF QUALITY COST MEASUREMENT AND RESEARCH RATIONALE

Considering reviewed literature, with the work of the IAQ Project Team (1995) as the single most important source, and personal experiences, the research rationale is given by four main observations. The reason for each observation is stated in consecutive sections.

➊ Traditional quality cost systems are mainly internal company focused and reactive by nature. Improvement activities are prioritized according to internal measures, and negative feedback from the customers after problems have occurred. This may lead to sub-optimization, not always beneficial to the customer. When indirect quality costs are included, the list of priorities may change.

➋ Performance measurement and top management decisions are principally based on traditional accounting information, not quality cost measurements. Existing quality cost systems are not linked sufficiently to other business performance measures, and they are often sub-systems used by middle management and operation supervisors in individual departments. Traditional accounting information is not adequate to monitor and direct quality improvement.

➌ The original quality cost categories are not as valid today as they were when they were first advocated.

➍ The foundation of quality cost measurement has changed during the last decade, justifying a change in focus.

2.1.1 Focus of Traditional Quality Cost Systems

The strategy in traditional quality cost models has been a direct attack on failure costs in an attempt to drive them to zero. Then invest in the "right" prevention activities to bring about improvement, and reduce appraisal costs according to results achieved. Prevention efforts are continuously evaluated and redirected to gain further improvement (ASQC Quality Cost Committee, 1990). This approach is thoroughly documented in various papers. They all have a common denominator (IAQ, 1995): "In workshop B there was $500 worth of failure costs per week. The root cause was detected and eliminated at an investment of $5000. With 50 working weeks per year, the pay-back was 5:1 in the first year alone." This approach is useful as a mean to initiate quality improvement programs, *but not as a basis for strategic management decisions*. It is difficult to separate specific prevention activities from everybody's basic duty of improving their work. It is also difficult to determine if appraisal activities are a part of the production process (do they add value to the product or not?), especially when inspection is asked for by the customer. Appraisal and prevention costs are useful for internal measurements within a department, but require thorough process knowledge to be applicable, and should not be added up for the company.

The focus of traditional quality cost concepts is to avoid errors and failures, which is mandatory for a company, but it should never be the ultimate goal. Zero defects do not necessarily lead to customer satisfaction and loyalty, life cycle costs or user costs of the product have to be considered as well. As a result of the increased quality consciousness among customers, and tougher competition, only the best companies will survive in the long term. To do so, they must not only fulfill specified customer requirements and produce efficiently, they must also be able to understand and meet latent needs and be able to improve even if the actual customer is not complaining. Traditional quality cost concepts do not address this aspect adequately. Quality cost efforts still largely consist of analyzing factory costs that are easily obtained from accounting records (Atkinson, et. al., 1991). By solely focusing on preventing errors and failures, quality cost concepts also fail to see that lost production does not only arise when things are made wrongly, but also when wrong things are made (Figure 2.1). The only acceptable level of performance is the upper right box, right things made right, that is, defect free without corrective action. The two lower boxes in the figure are addressed by existing quality cost concepts when they are used in manufacturing, while the upper left box is normally ignored in any quality cost context.

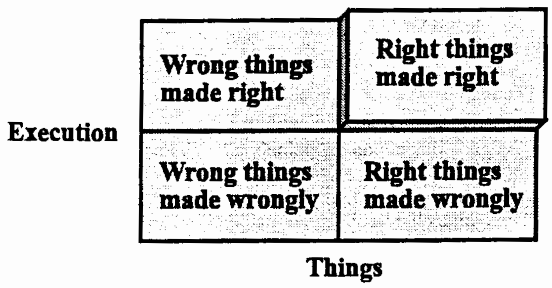


Figure 2.1 Right and Wrong Matrix (IAQ, 1995)

External failure costs are often used as quality system surveillance, where high external failure costs indicate that the quality assurance system is not working sufficiently. The problem with this type of measurement is that they are reactive by nature. The failure has already appeared, and the customer has already been affected and most likely become dissatisfied. Another problem is that not every customer complains when they receive a unsatisfying product or service. The rate of complain is especially low for inexpensive consumer products and services, and the customers simply take their business elsewhere. The White House Office of Consumer Affairs reported in 1982 that 96 percent of unhappy customers never complain about discourtesies, but 81 percent will not buy again from the business that offended them (Harrington, 1987). The company will never learn that there are a problem and are unable to make improvements, and the customer is most likely lost. Feigenbaum (1989) reported in Executive Excellence, "Today, there is little tolerance for the time and cost of any failures. The lifestyle of consumers and the work processes of companies now depend almost completely upon the reliable, predictable operation of products and services. One-third of all resolved customer complaints requiring product service leaves a dissatisfied customer. The hard arithmetic of this quality effort on return sales and market share is that when a buyer is satisfied, he tells 8 other buyers; when he's dissatisfied, he tells 22." Quevedo (1991) have estimated that the value of one satisfied and life-time loyal customer is $140,000 in revenue for an automobile producer, $80 annual profit for banks, and $4,400 annual revenue for the local supermarket.

Managing quality cost begin with a general understanding and belief that improving quality performance, as related to product or service, and reducing quality costs are synonymous. The next step is to recognize that these improvements and cost reductions have to reflect the customers' needs and requirements. *Increased internal quality performance has to be measurable as increased customer loyalty, increased re-purchase intentions, and accordingly* *increased market share and profit*. Companies that have achieved substantial reductions in their quality costs by using traditional quality cost models, and analyzed the impact on customer satisfaction, have not found a satisfying significant relation (Nawrocki, 1996). That implies that present quality cost models do not link internal improvement to customer satisfaction adequately, and internal improvements may be of limited benefit to the customer. Deming (1994) said "We do not wish to have an unhappy customer, but it will not suffice to have customers that are merely satisfied. They may switch and come out better for the switch." This supports that the quality cost system and the quality improvement process must be based the customer's needs and requirements, not the manufacturer's internal processes and conjectures of what the customer thinks is important.

2.1.2 Performance Measurement

Conventional reporting and traditional cost accounting can be a barrier to continuous improvement (TQM). Standard cost systems usually institutionalize waste by relating it to a pre-established standard. Usually a substantial amount of failure cost (included rework) is already hidden in these figures (IAQ, 1995). A certain percentage rejects may be considered necessary in a production process, and as long as this number is not exceeded, no failure is recorded. Any efforts to improve this process will not be undertaken since there is no focus on improvement through the standard cost system. Such pre-established standards do not exist for administrative activities, and from the financial point of view, no discrimination is made between doing something and doing it over. If a report is rewritten or an invoice is redone, no financial consequences are recorded. All activities are dealt with in the same manner (IAQ, 1995). Traditional cost accounting systems emphasize stability, control, and efficiency of isolated machines, workers, and departments through the use of tools like standards and variance reporting (Kaplan, 1995). Cost accounting systems report events that have occurred in the past, often with a considerable time delay, and they are often too slow to serve as performance measure. To rely solely on these systems as basis for management decisions can be compared to driving a car sitting in the rear seat looking backward. *While production systems and resource requirements have changed considerably during the last decade, accounting systems is mainly the same as in the first part of this century*. This implies that accounting systems might have lost their relevance, and new systems that focus on managing the activities that drive costs instead of managing costs are required (Johnson and Kaplan, 1987). Dr. Juran (1993) claimed that there was a quality crisis in American industry and that the effort undertaken to overcome this crisis often failed. The reason is that the responsibility for quality has been taken from the CEOs, starting with the evolvement of Taylorism, via central inspection departments, to quality departments. The people who implemented quality improvement programs did not develop new measures for quality, or they relied on financial measures and not measures of customer satisfaction and loyalty. The lack of measures resulted in a too late respond to the quality crisis and they learned of their quality problem only after severe damage had been done.

Most accounting systems are designed primarily to value inventory for financial and tax statements, and have not kept pace with the profound changes occurring in modern manufacturing (Gupta and Campbell, 1995). Accounting systems are based on cost centers that follow organizational lines of authority, while quality improvements are cross functional with focus on the production process. From an accounting and control standpoint, it is difficult to determine who will be held responsible for quality costs (Reynolds, 1989). Traditional accounting systems are not able to provide all the required information for strategic decision-making and monitoring of the quality improvement process. Intangible quality costs like customer dissatisfaction and lost sales opportunities are not considered costs in a traditional accounting sense and not intercepted by traditional accounting systems (Margavio, Fink and Margavio, 1994; Kim and Liao, 1994). Reducing these opportunity costs are the primary focus of quality improvement, so managers cannot rely exclusively on figures from the accounting function (Kaplan, 1988). James Houghton, chief executive of Corning, asserts that his company's total quality program, which was a major strategic thrust for Corning during the 1980s, *was virtually impossible to defend based on its impact on current profitability measures* (Aaker and Jacobson, 1994).

A comprehensive survey accomplished by Kumar and Brittain (1995) in the British manufacturing industry in 1995, revealed that while 79 percent of the companies had an opinion about their quality costs, only 27 percent used the appraisal, prevention and failure categories. Fifty-nine percent of the companies presented quality cost information at management review meetings. Another observation is that 59 percent of the companies that had an opinion about their quality costs placed their quality cost figures at less than 5 percent of total sales. This study substantiates the supposition that top management does not use quality costs as a measurement tool, and that the focus is on internal processes.

Traditional quality cost measurement based on prevention, appraisal, and failure costs has become obsolete along with traditional accounting. Toffler (1990) describes a society that is shifting from industrialization and mass production to an information society. *The new focus will be on mass customization and industrial manufacturers will have to focus their business on customer requirements, needs, and expectations, and measure their achievements through customer satisfaction and loyalty.* Measures have always been a central component of quality control and later quality improvement, but the common denominator has been that those have been measures of technical features. *A need for measurement on the managerial level is now emerging, and these measures have to be externally focused, not on internal processes and physical characteristics of the product.*

2.1.3 Validity of Cost Categories

Failure Cost

Failures are often eliminated according to the Pareto-principal, where the most severe failures with the largest economic consequences (according to traditional accounting) are eliminated first. This approach is adequate at the start of a quality improvement program, but not over time if the company wishes to satisfy and ultimately "delight" their customers. When all the "important few" errors and defects are eliminated, many minor causes have not been addressed. Isolated, based on the traditional economic theory, nothing should be done with these errors and defects. There is no point spending $5000 to eliminate the root-cause of an error or defect causing an annual cost of $50. The problem is that there are thousands of these errors and defects, each quite insignificant, but together they are considerable. The customers are not willing to accept these minor failures anymore (IAQ, 1995).

A related problem is that failure costs are driven by defect rates, and these defect rates are defined as products with some characteristic that when measured falls outside specification limits. No distinction is made between the level of quality of parts or products that have measurements equal to or close to the target value and equal to the upper and lower specification limit (Diallo et. al., 1995). Specification limits are not always based on customer requirements and needs, but on convenience and internal company opinions about their customers needs and the performance of the company's production equipment. This approach is not in line with the concept of continuous improvement and TQM (Fink, Margavio and Margavio, 1994).

Prevention Cost

The most severe problem with prevention cost can be found in the underlying philosophy. It implies that it is necessary to distinguish between normal, error-prone activities, and some extra effort to perform them error free that carries additional costs. Another problem is that an error only occurs when a characteristic exceeds some tolerance limits, and prevention activities will not be undertaken as long as the characteristic performs within these tolerance limits. This philosophy is based on former systems of mass production with long production runs, high defect rates, and the use of Acceptable Quality Levels (AQLs). This approach is not in line with the TQM philosophy and the zero-defect approach (IAQ, 1995).

One of the basic assumptions for TQM is that every activity in the company is a part of a process, that should increase the value of what is done in the company by its technical, administrative, and sales functions. This scope was not covered in the original quality cost concept, embracing only manufacturing processes. If every activity is considered a part of a process, each process must be designed to deliver defect free and perform error free. Separating specific prevention activities from normal design activities is becoming impractical and very difficult. The IAQ project team (1995) have recommend that any shortcoming, regardless of where it surfaces, should be called an error, mistake, defect, or failure to oblige to the TQM philosophy.

Porter and Rayner (1992) point out that "Prevention of problems is one of the prime functions of management, and it will always be difficult to decide which activities represent prevention of quality failures and those which are just good management." Error free design and work performance are normally the duty of everyone in an organization and the extraction and definition of prevention activities is difficult, if not impossible. This is explained by two examples from the IAQ project team (1995):

- An old machine is replaced by a new one. It has both a higher output and less variability. What portion of the investment, including training of operators and installation, is for quality improvement?
- If retraining an employee to enable him to perform better is considered to case a prevention cost, why do not the wages of a genuinely better qualified person?

Individual defect prevention is of outmost importance, and it has been thoroughly documented that prevention activities are one of the most profitable ways a company can use their resources (Gupta and Campbell, 1995; Chauvel, 1995). The definition and reporting of prevention costs is more questionable. Juran (1988) points out that "Continuous measurement of prevention costs can be excluded in order to (a) focus on the major opportunity, i.e. failure costs, and (b) avoid the time spent discussing what should be counted as prevention costs." Recent reports from Japan (Ito, 1995) support this view. Several Japanese companies have recently developed quality cost systems that focus on failure costs and regard prevention and appraisal costs as unimportant items. This is based on Company Wide Quality Control (CWQC) that impedes separating quality control from other activities. *The reason for not including prevention costs in the new model can be summarized as*:

- Individual defect and error prevention are of outmost importance, but this activity is an integrated part of everybody's work and thereby included in their salary. The standard of every activity is error free, and preventing errors from occurring do not inflict additional costs.
- Investments in facilities, materials, procedures, and training can be called failure prevention, but it is very difficult to separate these activities from other purposes like more output.
- Prevention costs are difficult to classify and complicates the overall cost picture.

Appraisal Cost

EOQ(C) (1989) have defined appraisal cost as "The cost of assessing the achievement of specified quality requirements" with the note added "Appraisal cost may include the cost of inspection, test and control, performed during or in completion of design and development, of process control during manufacturing and installation and other cost.". This definition includes practically all test and measuring activities, whether done by the quality department, third-party specialists, engineering and production people, or fully automatic test equipment. The difference between labor and appraisal cost becomes very diffuse (IAQ, 1995). Another problem with the traditional approach is that technological advance in automatic gauging, together with other factors such as high labor costs, flexibility, and reliability, are resulting in a greater number of companies investing in in-line appraisal or measurement systems. Appraisal costs in the new manufacturing environment have become relatively fixed, when equipment is in place there is little variation in appraisal costs whether a few or all units are inspected (Diallo et. al., 1995). It has become very difficult to determine what is appraisal and what is process feedback that is an integrated part of the manufacturing process. The IAQ project team (1995) states that the necessity to inspect and test is ultimately the direct consequence of the (possible) presence of errors and defects, and that these costs should be put under the more general term of failure costs, even if as a separate item. *This does not include such elements as a lathe operator performing inspection to find out if more metal needs removing, and inspection done for process control purposes. These elements should be regarded as an integrated part of the process.* This approach is supported by Juran (1988), who said that if 100% sorting inspection is required by inadequate processes, these costs should be classified under internal failure.

If appraisal is customer ordered, it has to be considered a requirement that must be fulfilled as any other requirement specified in the contract, and viewed as any other process. These processes should still be monitored regarding quality costs since they might hold considerable potential for improvement. The customer may not have sufficient knowledge of the production process, and require non-optimal or even unnecessary appraisal activities only causing additional costs. If the manufacturer would have made this appraisal anyway, only the additional work should be excluded from the appraisal cost measure. *The appraisal cost element has been excluded from the new PQC model based on the following observations*:

- There is no optimal value for appraisal costs. A high figure may indicate badly performed production or an intrinsic necessity of the process. Using appraisal cost require thorough process understanding, and reporting an aggregated figure to top management serves no useful purpose. Appraisal costs should only be used as indicators of potential improvement of individual processes.
- Appraisal costs that are a direct consequence of inadequate processes should be recorded as failure costs.

- The cost of customer ordered inspection and testing should be considered separate processes and not viewed as appraisal activities. These activities should be treated as any other process and reported separately to display improvement potentials.

Indirect Costs

Indirect costs (customer incurred costs, customer dissatisfaction costs, and loss-of-reputation costs), as described by Harrington (1987), or intangible quality costs (Feigenbaum, 1961), have been emphasized as crucial for a company, but a satisfactory mean of measuring these costs have not been provided. Dr. Deming (1986) describes these figures as the most important one needed for management, but that they are unknown or unknowable. Atkinson et. al. (1991) make reference to research done by KPMG Peat Marwick showing that:

- 75% of quality costs are hidden from top management because they are not captured effectively or reported through the traditional accounting system (including failure costs).
- Substantially all of the hidden quality costs are related to the cost of poor quality. They often fall across departmental boundaries, so historically it has been difficult for organizations to assign ownership and responsibility for correction.
- The potential is tremendous for increasing profitability and cash flow by managing quality costs, particularly by focusing on the hidden costs. However, many companies will be unable to manage this hidden quality costs because they cannot measure them effectively.

Traditional quality cost concepts are measurement systems from the past, based on quality control theory. This may be the reason very few companies have quality cost systems that are utilized by top management to make long term strategic decisions (Kumar and Brittain, 1995). It is felt that in order to upgrade the quality cost concept to a strategic management tool, based on the TQM philosophy, indirect costs have to be made measurable and knowable, which is one of the main objectives of this work.

2.1.4 Foundation of Quality Cost Measurement

From the origin of quality cost measurements, on of the main purposes have been to use quality cost data to convince top management that they have to initiate a quality improvement process and focus on quality as an important business parameter (Juran, 1988; Harrington, 1987; Feigenbaum, 1983; Dale, 1994). During the last decade, the understanding of the importance of quality has changed considerably in western industry, and this objective is not as important as it was when it was first advocated. More and more companies have realized that quality is maybe the most important factor to gain competitive advantages, and that they have to start quality improvement programs if they are going to stay competitive (Carr, 1995). They do not need quality cost information to be persuaded of the importance of quality, they need quality cost information to direct long term improvement efforts.

The second objective for introducing quality cost systems, to identify opportunities for improvement and cost reduction, to provide a better return on the problem solving effort, is valid when companies start their quality improvement process, but not in the long run. When all major failures have been eliminated, traditional quality cost systems do not provide the necessary information for further improvement. Considering traditional accounting principals, further improvement is not profitable.

Quality cost measures have been emphasized as a mean to measure the efficiency of day to day quality management in line organizations, but it is believed that this is not necessary. These organizations have appropriate measures like failure rates, number of defects, and down time. Translating these measures to costs does not add any significant value in organizations that are dedicated to quality and quality improvement. They need an overall picture displaying how they meet their customer needs and requirements, and how their quality improvement effort influence customer satisfaction and loyalty.

2.2 PURPOSE OF THE RESEARCH

The purpose of the research has been to develop a *customer and process focused top management tool*, able to direct and display the results of quality improvements based on PQC measurements and the underlying processes causing costs. The input to the model is customer requirements, needs, and expectations, and the monitoring of costs focused on processes that influence these requirements. The following elements are emphasized:

- PQC data has to be easily accessible to top management in their strategic decision-making process, and serve as a measure for customer satisfaction and loyalty.
- The output of the model has to reflect the fulfillment of customer requirements, needs, and expectations so improvement activities can be directed to maximize the benefit for the customer.
- The model has to be process focused and able to trace costs across functional boundaries.
- Overhead costs and costs due to poor process performance have to be a part of the overall cost picture.
- Activities that are critical for meeting customer requirements, needs, and expectations have to be monitored more thoroughly than in previous models.

The development of the new poor quality cost model can be divided into three distinct parts:

❶ The theoretical development of the model and its individual elements, described in Chapter 3, 4, 5.

❷ Testing and verification of the model on data from a production environment to reveal shortcomings and difficulties, described in Chapter 6.

❸ Full scale implementation of the model. This part is beyond the scope of this work, but some suggestions have been provided in Chapter 8.

Appraisal and prevention costs were excluded from the model because they are difficult to define and trace, and complicates the overall cost picture. It is assumed that these cost elements have little significance in the long term decision-making process, and shall only be used as process surveillance for specific processes in each department.

The focus of the research has been on the development of the model and the methodology necessary to gather required data. As mentioned earlier, the practical implementation of the new PQC model is beyond the scope of the work since it would have required a comprehensive contribution and long time involvement from a manufacturing company. The emphasis has been laid on describing the new elements in the model and their interaction. Individual elements like customer surveys, data acquisition, Quality Function Deployment (QFD), Activity Based Costing (ABC), etc., are not described in detail since they represent established knowledge. *The novelty value of the research is how each component interacts to* *form an integrated PQC measurement system, and how Taguchi's loss function has been used to measure real PQCs based on unsatisfactory performance of characteristics that influence the customer's requirements, needs, and expectations. The methodology of estimating intangible PQCs have also been an important part of my work.*

3. NEW CUSTOMER AND PROCESS FOCUSED POOR QUALITY COST MODEL

Previous quality cost models have been reactive by nature and only recorded quality costs after a failure has occurred or a customer complaint has been received. Considering the shortcomings of the previous models (Feigenbaum 1956; Harrington, 1987), a new proactive model has been developed. Existing models have been altered to achieve a better customer and process focus, and to better elucidate where problems are located. The appraisal and prevention elements have been removed, since they are difficult to measure and/or have limited application in the strategic decision process. *However, it is still important to measure these elements for internal operational use in each department.*

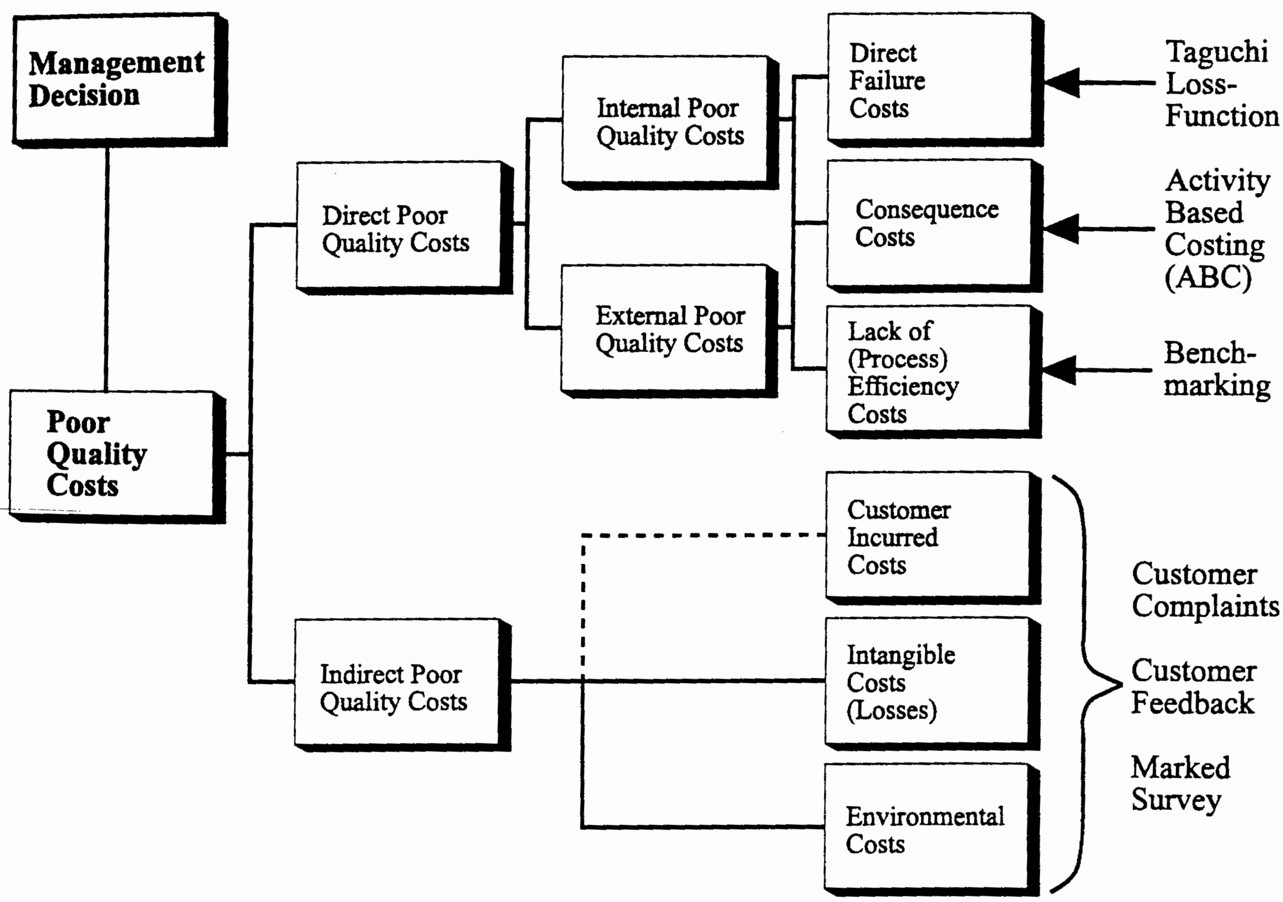
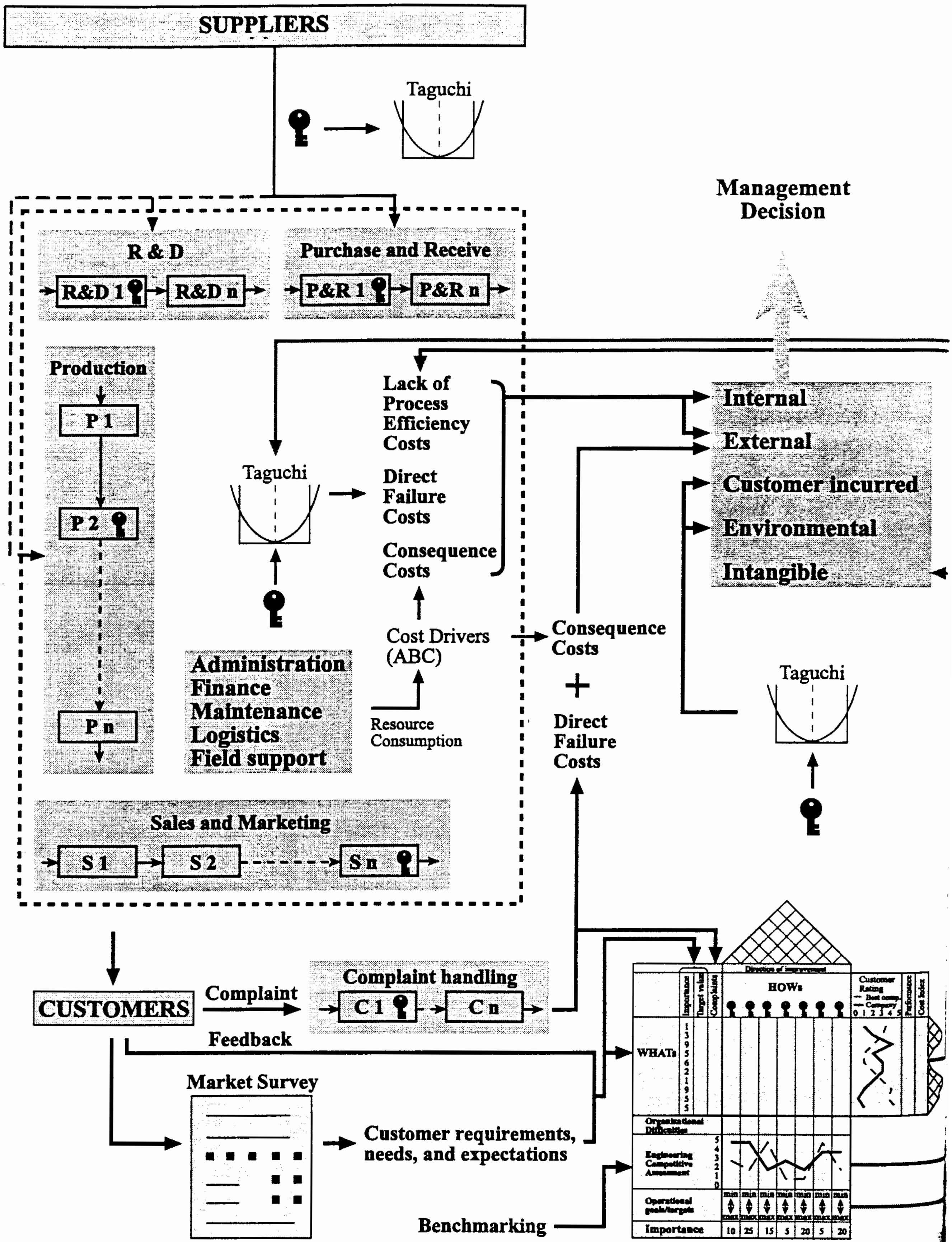


Figure 3.1 New Customer and Process Focused Poor Quality Cost Model

The model divides PQCs into two main categories of direct and indirect PQCs. The direct element consists of cost categories that are monitored and perceived within the company, while the indirect element contains costs that are first perceived by the customer but subsequently returned to the company as lost market shares. The bases for both elements are customer requirements, needs and expectations. Direct PQC is split into internal and external PQC, which are both divided into the same three elements of direct failure costs, consequence costs and lack of (process) efficiency costs. Figure 3.1 shows the structure of the PQC measurement system and Figure 3.2 the integration of each element in the model into a quality cost system. Each cost element is described in this chapter, while the lower part of Figure 3.2 (the QFD matrix and market surveys) is described in Chapter 4. The use of Taguchi's loss function is explained in Chapter 5. The dotted rectangle in Figure 3.2 represent the company.



= Key process parameter as described in chapter 3.3.2

Figure 3.2 Integrated Poor Quality Cost System

3.1 DIRECT POOR QUALITY COSTS

3.1.1 Direct Failure Costs (Figure 3.1)

This element embraces all direct financial consequences of every error, defect, mistake, fault and failure discovered before shipment to the customer (internal failure), and all direct costs associated with claims, customer rejects, warranty administration and lawsuits as a result of problems that are discovered after shipment (external failure). Traditionally, the monitoring of the failure cost element has been based on target values with defined tolerances around these targets. It is still a common practice in the industry to assign tolerances by convention (Kackar, 1985), and not based on the requirements of the customer. The practice of using a target value and tolerances conveys the idea that a user remains equally satisfied with all values of the performance characteristic at an interval, and then suddenly becomes completely dissatisfied the moment the performance value slips out of this interval. This practice can lead to increased manufacturing costs if the tolerances are too narrow (internal failure costs) or increased performance variation and reduced product lifetime if the tolerances are too wide (external failure costs and indirect PQCs).

Direct Internal failure costs are made up of two main groups of error, defects, mistakes, faults and failures based on their influence on the performance of the final product or service.

1. *Non-critical failures that have no influence on the performance of key characteristics that affect the core product or service as identified by the customer.* They embrace activities like redesign of a product in pre-production stages, rewriting internal reports, errors in salary payments, etc. These non-critical failures represent an improvement potential for the company that will lead to reduced production costs, but such improvements will never be detected by the customer as long as they do not result in reduced sale prices or improved reliability of delivery. Non-critical failures are measured according to traditional quality cost measurement based on tolerances and predetermined standards of performance. Costs accumulate when process characteristics exceed a predetermined standard. *This element has not been emphasized in the case study described in Chapter 6, since these measures are done according to traditional theory and the novelty value is limited.*

2. *Critical failures that have a direct influence on the performance of key characteristics and thereby the fulfillment of customer requirements.* These failures are measured for all critical process steps through Taguchi's loss function. The loss function is based on the idea that any deviation from a target value for a performance characteristic leads to a loss for the society (Albright and Roth, 1992). These losses can be classified in two main categories, the loss due to performance variation and the loss due to harmful side effects of the product. Performance variation is variation in the core function of the product, that is the dependability of the product. Harmful side effects are elements like noise, vibration, pollution, etc., caused by the product but that does not influence the core function (Taguchi, 1986). The latter is partly covered by Environmental Costs in Figure 3.1. The essential components of the loss due to performance variation are the loss across different units of the product, and the loss during the life span of the product under different operating conditions. Loss functions have been constructed based on actual losses at points where the performance of the key process parameter changes, based on internal company costs (described in Chapter 5.2 and Chapter 6.3). A quadratic

function has been derived and used between each different point of performance. Chapter 5 provides a detailed description of how the loss function has been utilized to monitor PQCs.

Using customer requirements, needs, and expectations as an input to process surveillance (the loss function), and prioritizing process improvements based on PQCs monitored by the loss function, enable the company to direct their improvement efforts to achieve maximum yield for their customers. This approach to monitor failure costs brings the PQC concept more in line with the TQM philosophy of customer focus and process understanding and control.

3.1.2 Consequence Costs

Consequence costs are all additional costs related to direct failure costs like administration, disturbances in current and related processes, additional planning, readjustments, etc. Overhead costs are assigned to each failure and process with the use of Activity Based Costing (ABC). ABC is an accounting tool that allocates costs to specific activities based on each activity's resource consumption by the use of cost drivers. Cost drivers can be direct labor cost per m^3, direct material consumption per m^3, indirect material consumption per m^3, maintenance per m^3, etc. This element is just briefly described to provide the overview necessary to understand the model (Figure 3.2), since the company who supported the case study did not have an operational ABC system. A simplified approach to ABC has been developed and used in Chapter 6.3.1 to link costs to activities performed due to poor product performance. The approach is described in Chapter 5.4.1. A more detailed elucidation of the use and implementation of ABC can be found in accounting literature like Brimson (1991) and Cooper et. al. (1992).

3.1.3 Lack of (Process) Efficiency Costs

Lack of (process) efficiency costs are the financial result of non-optimal processes, that is insufficient process performance compared to chief competitors, or theoretical optimal process performance. This element focuses mainly on the costs incurred when wrong things are made right (Figure 2.1, page 14), as well as processes with unnecessary process steps and process down-time. Key process parameters should be evaluated against competitors' processes or similar processes in other companies (Competitive or Functional Benchmarking), and evaluated against theoretical optimal performance of current processes to reveal improvement potentials. Unnecessary process steps that might be detected during the process analysis are displayed as 100% loss. For example, if a chemical process gives an output of 90 kg per hour under given conditions, and the competitor's process gives an output of 95 kg per hour under the same conditions, 5 kg per hour should be recorded as deviation. The theoretical output of the process should also be considered so that the company can exceed the performance of their competitors. The time horizon for utilization of this information is longer than for failure costs because improvements often require rethinking and heavy investments. The reason for including lack of (process) efficiency costs are the process orientation in the TQM philosophy. These costs represent different levels of performance for processes under statistical control, and should be a main target for quality improvement.

Competitive Benchmarking is the process of examining a competitor's product or service according to specified standards, and compare it to one's own product or service, with the objective of deciding how to improve one's own product or service (Cohen, 1995). *Functional (or Process) Benchmarking is an evolution of Competitive Benchmarking where the focus has* *shifted from products to specific functions or processes in the company* (Andersen, 1995). In this model only key process parameters that have most impact on product characteristics, as emphasized by the customers, are of interest for benchmark studies. There exist several different models and approaches for the use of benchmarking, and a good source is Camp (1989) who is considered one of the pioneers within the field. Andersen (1995) provides a thorough overview of the development of benchmarking and its application. A further application of benchmarking is beyond the scope of this text, since a full benchmarking study is quite comprehensive and requires full participation from the manufacturer.

3.2 INDIRECT POOR QUALITY COSTS

3.2.1 Customer Incurred Costs

Customer incurred costs embrace all direct financial consequences experienced by the customer as a result of unsatisfactory quality supplied by the producer. This element covers mainly the same costs as critical internal failure cost, described in 3.1.1, does for the manufacturer. Elements included are:

- Loss of productivity while equipment is down.
- Overtime to make up production because equipment is down.
- Backup equipment needed when regular equipment fails.
- Additional production planning as a result of delayed incoming materials.
- Additional acceptance testing.
- Travel costs and time spent to return defective merchandise.
- After warranty costs.
- Administration of complaints.
- Etc.

Customer incurred costs will per definition always affect the customer, and they have thus been monitored by the loss function in the same manner as internal and external failure costs (see section 3.1.1). The loss function for customer incurred costs is based on the customer's perception of when a customer requirement is met to satisfaction and when it becomes unsatisfactory, along with the financial consequences of this insufficient performance. Customer incurred costs can far exceed the total purchasing price during the life cycle of a product. The importance of this element will increase as customers become more conscious of their purchase decisions.

3.2.2 Intangible Costs (Losses)

Intangible costs cover both customer dissatisfaction costs and loss-of-reputation costs. *Customer dissatisfaction costs are costs that occur when a customer refrains from re-purchasing a product because he or she is dissatisfied with the product's overall performance. Loss-of-reputation costs occur when customers refrain from buying any products from the manufacturer, based on their poor experience with one specific product.* The latter reflects customers' attitude towards the company rather than toward a specific product. Harrington (1987) indicates that customer dissatisfaction is a binary thing. Customers are either satisfied or dissatisfied. Customer dissatisfaction costs are made up by two main elements: lost sales because the customer refrains from re-purchasing the product, and lost sales because the customer influences other people not to buy the product. Loss-of-reputation costs are directly linked to customer dissatisfaction costs and occur depending on the company's product range and the similarity between different products. Loss-of-reputation costs have to be estimated for the entire company and distributed to different products. As opposed to customer incurred costs, intangible costs are difficult to measure and have to be estimated. When these costs have been determined they can be linked to performance through the QFD matrix as described in Chapter 4.7. The estimate of intangible costs for one product is based on customer requirements, the customers' rating of each requirement's importance, and the company's ability to meet each requirement compared to chief competitors. The approach is described in Chapter 4.7.

3.2.3 Environmental Costs

This element has been included to put emphasis on the increasing importance of consciousness regarding the environment. Environmental aspects of product and process quality have become increasingly important during the 1990s, and control over every process and product regarding the environment will be critical when ISO 14001 (1995) and ISO 14004 (1995) receive full attention. Environmental costs cover parts of harmful side effects of a product as described by Taguchi (1986). This part of the PQC model has not been further emphasized, and left as suggestions for further research.

3.3 BASIS FOR THE NEW POOR QUALITY COST MODEL

The new PQC model is based on:

- A thorough understanding of the customer's requirements, needs, and expectations (the voice of the customer), and the customer's perception of the ability of the product or service to fulfill and/or exceed their expectations.
- A thorough understanding of all processes necessary to fulfill, and if possible exceed, the customer's expectations. Every activity within the company is considered a part of a process, and each department or natural restricted part of the company is considered an internal customer and supplier, and can basically be treated in the same way as external customers and suppliers.

3.3.1 The Voice of the Customer

According to the work of Professor Noriaki Kano (1984) the overall spectrum of customer expectations and satisfaction can be displayed as in Figure 3.3. The horizontal axis shows how well the customers' expectations are met by the product or service, and the vertical axis shows the degree of actual customer satisfaction.

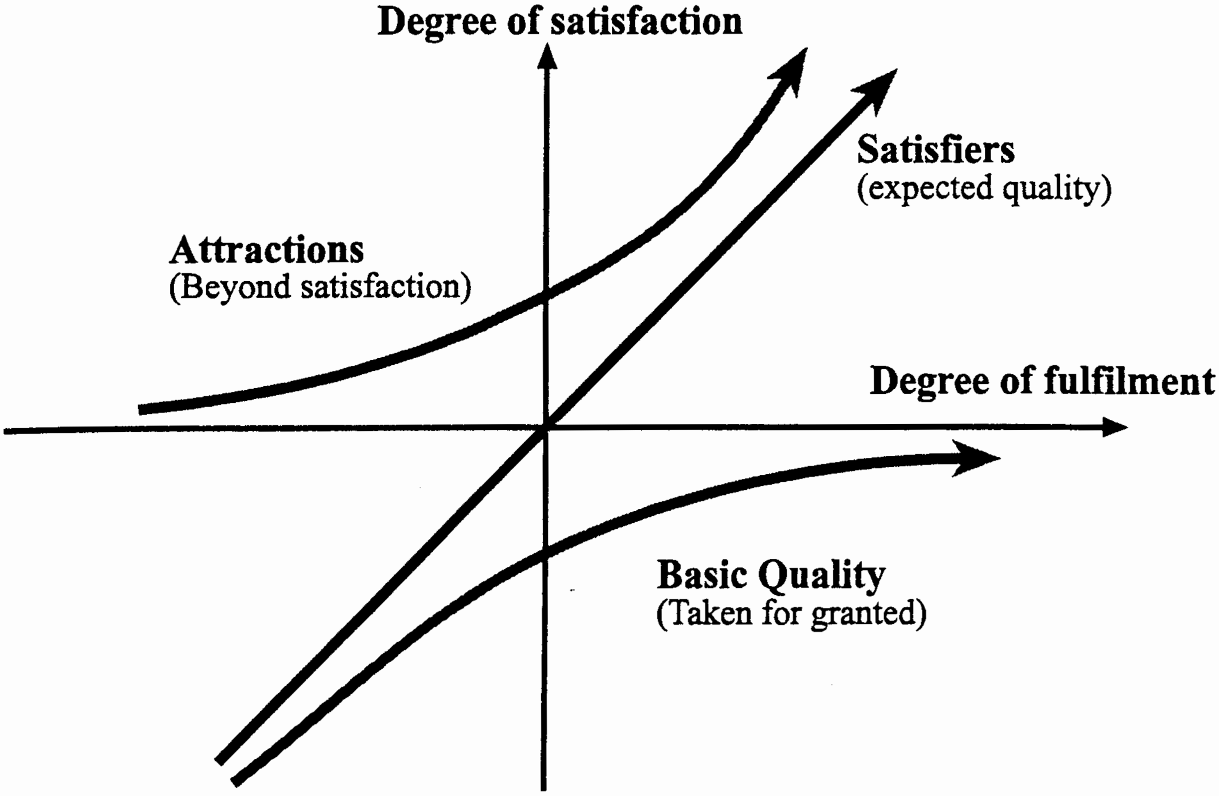


Figure 3.3 The Kano Model

Basic Quality requirements are expected met without further specification and are rarely mentioned by the customer. These basic quality requirements represent the core function of the product or service that is the basic reason for purchasing the product. Getting from A to B without any accidents is the core function of an air travel. Meeting these requirements alone does not lead to satisfaction, but failure to meet a basic functional requirement represents a built-in dissatisfier. Satisfiers are those characteristics that customers give voice to and require from a product or service in addition to basic characteristics. It is normally assumed that a high degree of obligingness to these characteristics leads to a high degree of customer satisfaction. These attributes tend to be easy to measure and therefore they become the benchmarks used for competitive analysis. No waiting in line during check-in would be a satisfier. Attractions are those attributes or features that go beyond the customer's expectations. Customers do normally not know that they desire this characteristic before it has been provided. Failure to provide attractions in a product or service does not lead to dissatisfaction, but providing them may lead to competitive advantages. Customer complaints, which traditionally are monitored through external failure costs, mainly reflect customer dissatisfaction as a result of the company's inadequacy to provide basic characteristics. How to gather the voice of the customer has been further emphasized in Chapter 4.1 and Chapter 6.

3.3.2 Process Understanding

A thorough understanding of every process within the company is the other basic requirement of the PQC model. It is critical to identify which process parameters that influence the quality of the final product, and how they influence it according to the customer's perception of product characteristics. The process understanding is also an important part in reducing lack of (process) efficiency costs. As a process evolves over time, additional systems may be added into current systems to screen or rectify deficiencies, building inspection and corrective steps into the process.

A process is defined as interrelated resources and activities that is characterized by a specific input, and a value-adding task that produces a specific output. Processing an invoice is one process, while shipping the product is another. A company consists of several processes that is linked together. *A sub-process is a part of a process consisting of consecutive activities that have natural limits to other sub-processes.* Writing the invoice is a sub-process of the overall processing of the invoice. *Process steps are each single activity within each sub-process.* For the invoice example, this can be proofreading the invoice. *Key characteristics are features whose variation has the greatest impact on the fit, form, performance, or service life of the finished part, product, or service from the perspective of the customer. Key process parameters* (🔑) *are measurable and controllable process parameters that contribute to variation in key characteristics,* and thereby how the product or service meets customer requirements as defined by the customer. Number of failures per invoice will be a measure of a key process parameter.

A work unit is a group of interdependent process steps that form one or more sub-processes. Processing an invoice is normally done by a work unit, but this administrative unit will normally have the responsibility for other sub-processes as well. One process may be composed of one or more work units. A work unit always receives some kind of input from other work units (internal suppliers), and delivers some kind of output to consecutive work units (internal customers). Each work unit can have several suppliers and customers, but they usually have only one supplier and one customer in most manufacturing processes.

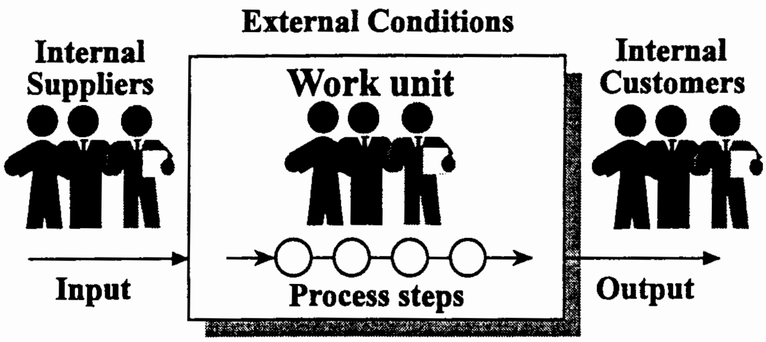


Figure 3.4 A Work Unit (SINTEF Production Engineering)

The PQC model requires the accomplishment of the following activities for each process in order to analyze its influence on customer requirements:

- Document the process as it is currently done in as much detail as possible (number, time, frequency, number of people, resource consumption, cost, etc.), and describe it in a flow chart. Special emphasis should be placed on non-value adding activities as they may be overlooked in business processes (Bruno, 1996). A Work Place Diagram graphically displaying the transportation activities within a process can be used to avoid the danger of overlooking non-value adding activities.
- Divide each process into sub-processes and each sub-process into individual process steps (activities).
- Identify work units within each process and determine every supplier and customer relationship including every administrative and supporting activity. Describe the output from each work unit. The work unit is used as a center of expertise during the remaining process mapping and analysis.

- Identify non-critical process steps within each work unit. These are process steps that can lead to severe internal PQCs, without influencing the product characteristics (failures are not transferred to the customer).
- Identify and describe each key process parameter within each critical process step that is assumed to have a direct influence on key characteristics and thereby the fulfillment of customer requirements according to the external customer's perception of the product or service. The same approach may be used for internal customers.
- Define numeric measures for each key process parameter able to reflect customer requirements, needs, and expectations through key characteristics.
- Determine consequences of deviation from the target value of key process parameters.
- Identify cost drivers within each process step leading to resource consumption.
- Set targets for key process parameters and determine acceptable variation of critical process steps based on information from the customer.

A more detailed description of the approach has been provided in subsequent chapters with emphasize on elements that are important for the overall model and the interaction of each component.

4. ALIGNING THE NEW POOR QUALITY COST MODEL

Quality Function Deployment (QFD), also called "the house of quality," is the single most important part in the new process and customer focused poor quality cost model. QFD is used to integrate elements in the system and to give response for performance measurement within the company (Figure 3.2, page 24). Basic descriptions of the use of QFD can be found in Cohen (1995), Day (1993), Bossert (1991). Only elements critical to the model are described in this text.

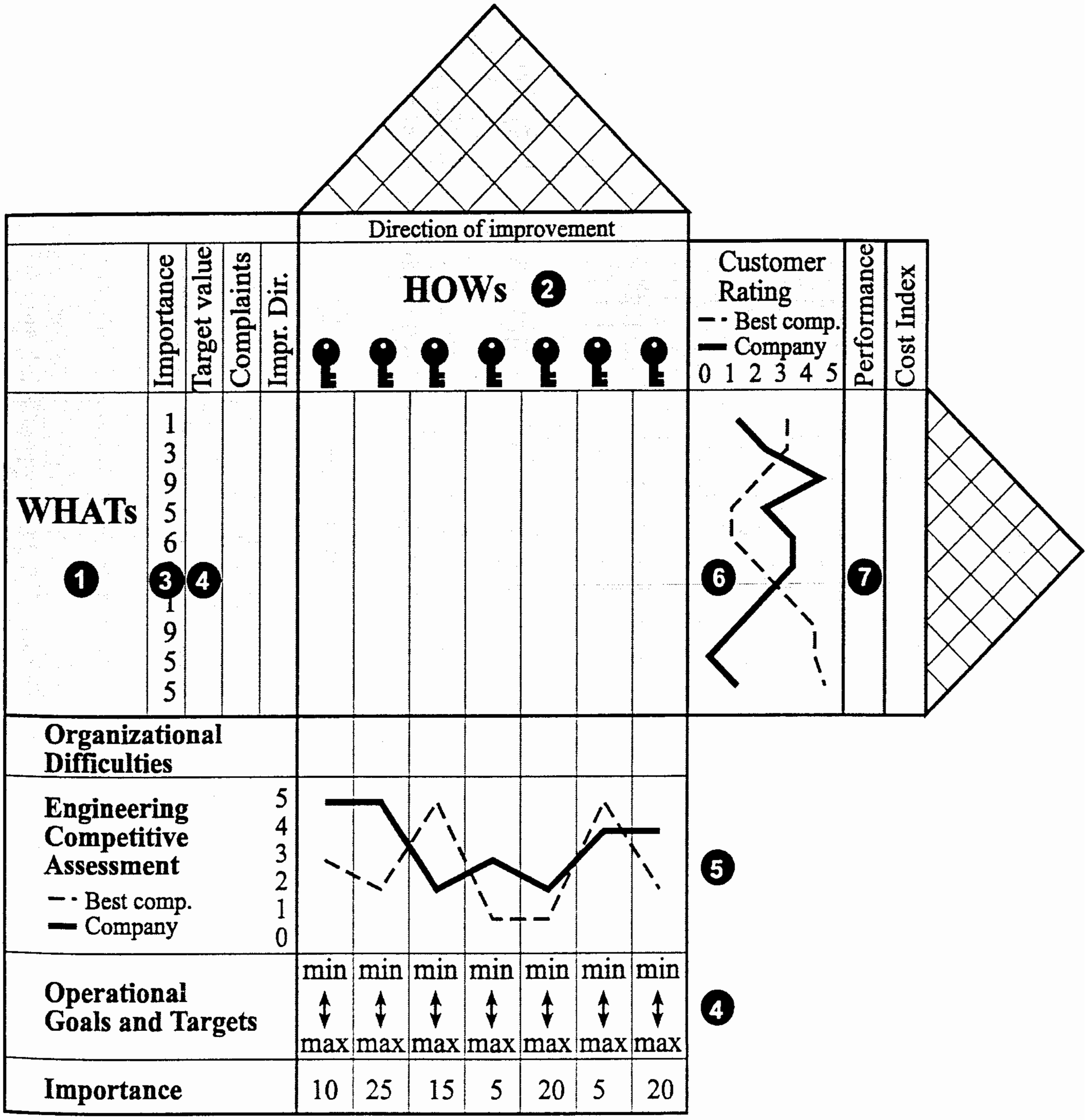


Figure 4.1 Linking the Customer to the Company

The term "house of quality" is normally reserved for only the first of four steps in the QFD process (Hauser and Clausing, 1988). Optionally the QFD process involves constructing additional matrices to further guide the detailed decisions that must be made throughout the product or service development process (Cohen, 1995). The QFD process is often presented as a four-phase model, often referred to as the Clausing "Four-Phase Model" (Figure 4.2); product planning (or house of quality), parts deployment (design), process planning, and production planning (Hofmeister, 1995; Quinlan and Byrne, 1995). Each matrix in the chain represents a more specific or a more technical expression of the product or service.

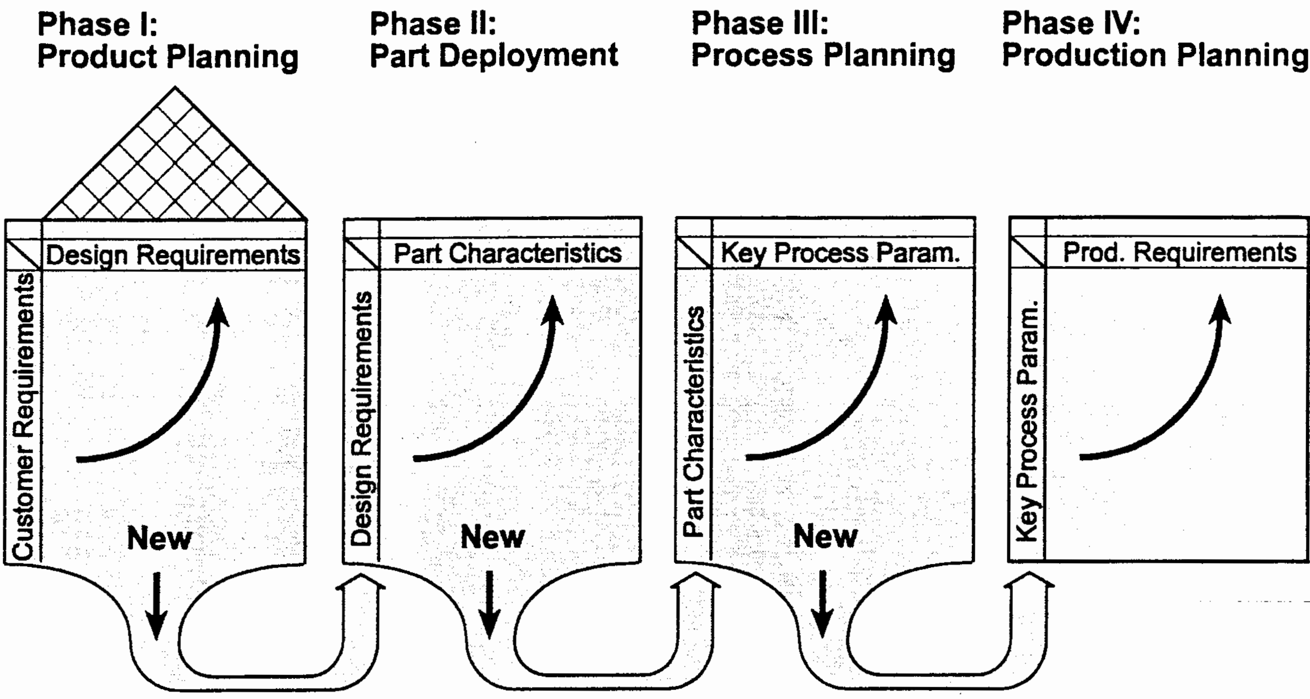


Figure 4.2 Phases in the QFD Process (Based on Hofmeister, 1995)

For the purpose of the new PQC model only customer requirements (from phase I) and key process parameters (from phase III) are required. Phase II and IV have been left out since the product or service already has been developed and is on the market. The QFD matrix used in the new PQC model (Figure 4.1) is based on a combination of Phase I and Phase III and utilized as the product planning or house of quality matrix (Phase 1 in Figure 4.2). This approach is applicable when the product or service concept has already been established and is in the market (Cohen, 1995).

The main elements in the QFD matrix giving input or output to the model are (Figure 4.1):

❶ Customer requirements, needs, and expectations (WHATs). This element is the foundation of the PQC measurement system and gives input to the model based on customers' perception of product or service characteristics.

❷ Technical responses (HOWs) that are a translation of customer requirements into technical terms. These technical responses are denoted key process parameters (🔑) and represent technical measures related to customer requirements (WHATs).

❸ Importance of each customer requirement as stated by the customer, used to estimate intangible costs (Chapter 4.7, page 42), and to assign priorities for improvement.

❹ Target values for each product or service characteristic as perceived by the customer, and operational goals and targets which are target values translated by the manufacturer to key process parameters. Operational goals and targets are based on the company's performance for each key process parameter (❺), the customers evaluation of the company's performance (❻), and the customers rating of importance of each requirement (❸).

❺ The company's perception of their performance for each key process parameter compared to their chief competitors based on competitive benchmarking.

❻ Customer rating which is the customer's interpretation of the company's ability to meet each requirement compared to competitors or chief competitor.

❼ Cost index used to estimate intangible PQCs for each customer requirement based on the customer's rating of the importance of the requirement ❸, and the customer's perception of the company's performance compared to their chief competitor ❻.

Each bullet (❶ to ❼) refers to different parts of the QFD matrix in Figure 4.1, and to the numbering of consecutive chapter describing each element (Chapter 4.1 to 4.7).

4.1 CUSTOMER REQUIREMENTS, NEEDS, AND EXPECTATIONS

4.1.1 Identifying Customer Groups

The customer requirement section of the QFD matrix is the single most important part of the PQC model (❶ in Figure 4.1). Before the company gathers the voice of the external customer, they have to determine who the customer is. Usually there are more than one category of customers requiring different approaches. The first step is to identify all possible external customers and group them into appropriate categories like markets, user types, or product application. The next step is to identify and focus on the key customer, the customer who is most important to the manufacturer regarding profit. This may also be an especially innovative customer that the company prefer based on their own long term development. Internal processes have to be optimized according to this customer's requirements, needs, and expectations. Requirements, needs, and expectations of other customer groups should then be included as long as they do not contradict with the key customers'. If there are more than one key customer group, Cohen (1995) suggests that each group should be included in the QFD matrix, with different weight indexes determined by the manufacturer indicating each group's importance (Table 4.1). The importance of needs within each group is based on the customers' requirements, and a weighted importance of needs is calculated as a product of importance of each customer group and importance of needs within the group.

Table 4.1 Weighted Customer Importance (Cohen, 1995)

Customer Group	Importance of Customer Group	Needs, Requirements, and Expectations	Importance of need within Group	Weighted importance of need
Distributor	0.50	Ease in ordering	0.32	0.16
	0.50	Just-in-time shipment from manufacturer	0.28	0.14
	0.50	Easy handling of shipped materials	0.24	0.12
	0.50	Easy stacking and storing	0.16	0.08
Retailer	0.33	Attractive package	0.30	0.10
	0.33	Minimum shelf space	0.25	0.08
	0.33	Product description on package	0.25	0.08
	0.33	Long shelf-life	0.20	0.07
End user	0.17	Easy to learn how to use	0.28	0.05
	0.17	Long shelf-life	0.24	0.04
	0.17	Long product life	0.17	0.03
	0.17	Safe to use	0.16	0.03
	0.17	Environmentally correct packaging	0.16	0.03

4.1.2 Identifying User Groups within each Customer Group

Each key customer group will normally consist of different internal user groups that have different, and often non-corresponding requirements to the product. A product might be sold through a purchasing department that has other requirements, needs, and expectations than the final user, and the product may be procured based on the wrong foundation. This may lead to dissatisfaction among the final users, which again may result in a discontinued use of the product and no re-purchase. It is therefore important to understand the requirements, needs, and expectations of every user group within each customer group, and how important each user group is for the purchase and re-purchase decision.

The case study in Chapter 6.1.4, page 66, revealed that different user groups in the company are more important for the manufacturer than different key customer groups. The study showed that requirements from different customer groups were similar and that it served no purpose differentiating them. When requirements from every customer were analyzed collectively by Dual Scaling[1] (Nishisato and Nishisato, 1994), different user groups emerged. These groups were independent of customer groups, but had different influence on the purchase or re-purchase decision. Each user group can be assigned a weight index by the manufacturer based on their influence on short term profit, in the same manner as for customer groups. An example is shown in Table 4.2.

Table 4.2 Weighted Importance for Different User Groups or Groups of Stakeholders

User Groups or Groups of Stakeholders	Importance of User Groups	Needs, Requirements, and Expectations	Importance of need within User Groups	Weighted importance of need
Service	0.50	Ease in ordering	0.32	0.16
	0.50	Just-in-time shipment from manufacturer	0.28	0.14
	0.50	Easy handling of shipped materials	0.24	0.12
	0.50	Easy stacking and storing	0.16	0.08
Use	0.33	Attractive package	0.30	0.10
	0.33	Minimum shelf space	0.25	0.08
	0.33	Product description on package	0.25	0.08
	0.33	Long shelf-life	0.20	0.07
Procurement	0.17	Easy to learn how to use	0.28	0.05
	0.17	Long shelf-life	0.24	0.04
	0.17	Long product life	0.17	0.03
	0.17	Safe to use	0.16	0.03
	0.17	Environmentally correct packaging	0.16	0.03

[1] Dual Scaling is a technique used to explore a hidden structure of categorical data through complex mathematical manipulation. Its basic idea has existed for at least half a century, and the technique has been proposed by many people under different names such as correspondence analysis, homogeneity analysis, Hayashi's theory of quantification, etc. (Nishisato and Nishisato, 1994). The Methodology is explained in Appendix D. Correspondence analysis is a more familiar term in Europe, and have been used instead of Dual Scaling.

4.1.3 Gather the Voice of the Customer

Input from customers are received either actively through surveys, customer conversations, focus groups, polls, etc., or passively through customer complaints. The latter mainly reveals basic requirements while the first identifies satisfiers according to Kano's model (Figure 3.3, page 29). The information needed are either of qualitative nature (what they require, need, and expect) or quantitative nature (how much). The following elements of information are required as input to the PQC model:

- Customers' requirements, needs, and expectations concerning the product or service (product characteristics). This part will primarily reveal satisfiers and to a less degree basic requirements (❶ in Figure 4.1).
- Additional features that the customers would like the product to have to increase their level of satisfaction (attractions).
- Other functions or tasks that can be performed by the product or service where they at present use other products or services (attractions).
- The customer's evaluation of the absolute importance of each product characteristic (❸ in Figure 4.1).
- The customer's perception of how the company meets his expectations for each product characteristic (❻ in Figure 4.1).
- The customer's rating of the overall performance of the product or service.
- How the customer rate the company's performance for each product characteristic compared to competitors or chief competitor (❻ in Figure 4.1).
- The customer's perception of when a product characteristic becomes unacceptable and when it is completely satisfying (❹ in Figure 4.1).
- The effect poor product or service performance has on the customer, both regarding his direct costs and his re-purchase intentions. This part is further emphasized in Chapter 4.7 dealing with intangible PQCs.

It is important to understand the customer's real needs when information is gathered, not only the customer's expressed need. For instance, a customer buying a computer may specify that he needs a 100 MHz processor and a 810 MB hard drive. This specification is based on previous experience with computers, and not necessarily actual needs. The customer needs a computer that is fast enough to perform required tasks, and have sufficient storage capacity. These requirements may be met by other product characteristics like internal memory, software, etc. It is therefore important to unhide and divide actual customer needs from technical solutions that should be provided by the company.

Basic requirements, satisfiers, and attractions (Figure 3.3 The Kano Model, page 29) have different impact on the company dependent on how the customer evaluates the company's ability to meet each type of requirement. Basic requirements have to be met to prevent dissatisfaction, while satisfiers have a linear relationship to customer satisfaction. The more satisfiers that are fulfilled, the more satisfied the customer gets. Attractions may lead to competitive advantages and can be used strategically to position the company in the market. Shiba et. al. (1993) have described how Kano identifies different types of requirements through a questionnaire. For each feature or characteristic, two questions are asked: how would you feel if the feature were present in the product, and how would you feel if the feature were not present in the product? To each question the customer can answer in one of five different ways (Table 4.3)

Table 4.3 Questionnaire used to Identify Preferences Regarding a Product Feature (Based on Shiba, 1993)

A How would you feel if this feature were present in the product?	1. I like it that way 2. It must be that way 3. I am neutral 4. I can live with it that way 5. I dislike it that way
B How would you feel if this feature were not present in the product?	1. I like it that way 2. It must be that way 3. I am neutral 4. I can live with it that way 5. I dislike it that way

Based on the answers from Table 4.3, product features can be classified into six categories: A - attractions, S - satisfiers, B - basic requirements, R - reverse, I - Indifferent, and Q - questionable. The first three categories are represented in Kano's model. The other three indicate situations where either contradictions exist in the answers to question A and B in Table 4.3 (Q): the customer is indifferent to whether the product feature is there or not (I); or the company's prior judgment of a feature being a satisfier is reversed by what the customer feels (R). The evaluation is done by using Table 4.4.

Table 4.4 Classification of Customer Requirements (Based on Shiba, 1993)

		A Feature present in the product				
		1. Like it	2. Must be	3. Neutral	4. Live with	5. Dislike
B Feature not present in the product	1. Like it	Q	A	A	A	S
	2. Must be	R	I	I	I	B
	3. Neutral	R	I	I	I	B
	4. Live with	R	I	I	I	B
	5. Dislike	R	R	R	R	Q

Customer preferences:
A - Attractions, S - Satisfiers, B - Basic requirements, R - Reverse, I - Indifferent, Q - Questionable

If a customer answers 1 to question A in Table 4.3 and 5 to question B, it can be seen by using Table 4.4 that the customer evaluates this feature as a satisfier.

Despite the use of Kano's questionnaire, attractions are difficult to identify through traditional customer surveys since they are normally unkown and unknowable to the customer. Hofmeister et. al. (1996) have identified four different methods of revealing attractions in a product:

- Operational Research where the manufacturers are watching their customers in their own environment. Through observations the manufacturer can see how their customers use the product, what frustrates them, what scares them, etc.
- Drastic improvement in performance for one customer need. An existing feature can become an attraction if the performance is improved far beyond competing products, especially if everybody is performing poorly.
- Eliminating or improving key process parameter trade-off can produce an attraction. A strong negative trade-off in the roof of the QFD matrix indicates engineering

compromises because of limitations in current technology. The elimination of strong negative correlation usually represents a major paradigm shift that result in attractions.

- Lateral (or Generic) Benchmarking where the company compares its product and performance against the best available benchmark, regardless of industry, and transfers features to its own industry.

4.1.4 Basic Classification of Customer Voices

The classification of different needs and requirements has to be done specifically for each QFD matrix, but a general structure has been suggested as a guideline. The primary level can be found by using Kano's model (Figure 3.3, page 29), where product characteristics can be divided into three main groups of basic quality requirements, satisfiers, and attractions. Basic quality requirements and attractions will rarely be mentioned by the customer, but it is of outmost importance to be aware of and include these product characteristics, since failure to provide them will lead to dissatisfaction. Basic requirements should be included as a check list and identified in the QFD matrix as a single row to limit the size of the matrix (Hofmeister et. al., 1996). A good source for basic requirements is customer complaint records, internal company failure records, and the company's experience with the product or service (see chapter 6.1.3). Attractions are not as important when the QFD matrix is used to measure PQCs as when it is used in product development. It is difficult to add attractions to a product or service in operation, but the element should be included to emphasize the importance of always looking for new approaches that can lead to a competitive advantage.

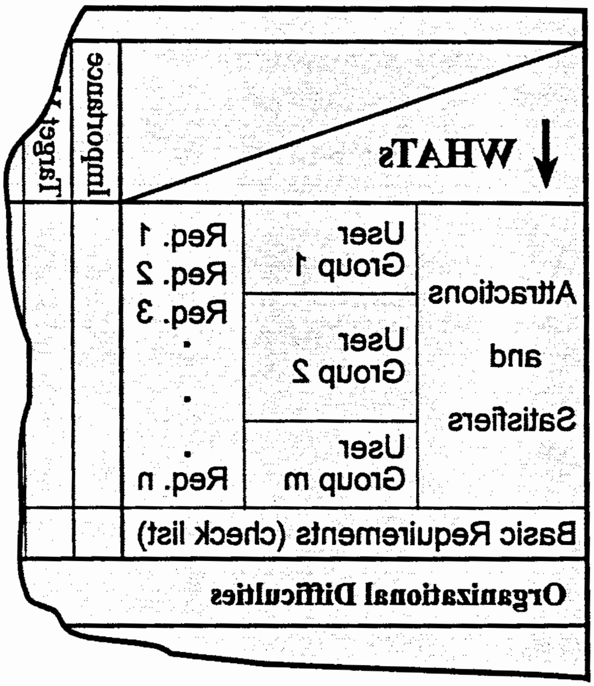


Figure 4.3 Customer Requirements

Both Cohen (1995) and Day (1993) have suggested using an Affinity Diagram methodology to identify the secondary level of customer requirements. The problem with this approach is that strong individuals in the focus group can influence the grouping too much based on their perceptions, and the structure may not reflect the needs of the different user groups in the company. In this work Dual Scaling[1] (correspondence analysis is a more familiar term in Europe, and will be used in the remainder of this text) has been used to identify different dimensions of requirements and thereby to form user groups as the secondary level in the customer portion of the QFD matrix. The last level is the actual requirements within each group.

Another way of classifying customer requirements has been developed by Robert Klein (Cohen, 1995). Klein uses both revealed importance and the stated importance of each requirement, need, and expectation to group them into the following categories:

Table 4.5 Klein's Model for Classifying Customer Requirements

Type of requirement	**Stated importance**	**Revealed importance**
Expected	High	Low
Low-impact	Low	Low
High-impact	High	High
Hidden	Low	High

Expected, low-impact, and hidden requirements are similar to the three quality dimensions described in Kano's model, while low-impact requirements have no counterpart.

Klein's model will not be used, but is included to provide an overall picture of possible ways of grouping customer requirements. My work is based on the model described in Chapter 4.1.1 and my own model described in Chapter 4.1.2. Correspondence analysis have been used to verify which model that produce the most reliable data for the grouping of customer requirements and the calculation of their importance. The analysis can be found in Chapter 6.4.

4.2 TECHNICAL RESPONSES (KEY PROCESS PARAMETERS)

Technical responses, or substitute quality characteristics, are the translation of customer requirements, needs, and expectations into the manufacturer's internal technical language (❷ in Figure 4.1). They are denoted key process parameters (🔑) and have been utilized to monitor and control the performance of each product characteristic (customer requirement) through the loss function (Chapter 6.2.1 and Figure 6.5, page 79). Key process parameters should not represent solutions (Day, 1993), at the same time as they are measurable and can be used as predicators rather than lagging indicators of customer satisfaction performance (Cohen, 1995).

The technical portion of the QFD matrix should be completed by a cross functional team with representatives from every function at the manufacturer who influences the quality of the product (Product Development, Production, Sales, Marketing, etc.). Each customer requirement will usually result in several key process parameters, and the team should focus on restricting the number of parameters to 1 to 3 per requirement. Otherwise the matrix will be too large and unwieldy, and the overview will be lost. Day (1993) suggests, as a rule of the thumb, that the overall ratio between customer requirements and key process parameters should be somewhere between 1 and 1,5.

The table in the center of the QFD matrix indicates the relationship between customer requirements and key process parameters (Figure 6.5). Relationships are normally indicated by symbols, where a filled circle ● indicates strong, an open circle O moderate, and a triangle ▲ possible relationship. When relationships are determined, it is important to work in columns. The team should look at each key process parameter and move down the column, asking "how would this key process parameter influence how the customer requirement is met?" Working in rows will give a relationship between almost any customer requirement and key process parameter. Only a week or no relationship between some customer requirements and key process parameters indicate that the customer requirement has not been adequately addressed. Every key process parameter should end up with a strong relationship to one or more customer requirements.

4.3 IMPORTANCE OF CUSTOMER REQUIREMENTS

Different user groups (Table 4.2) will normally have different requirements to a product or service. They will also most likely attach different importance to each requirement based on their specific needs (❸ in Figure 4.1). Another factor that is important for the manufacturer is that each user group may not have the same influence on the purchase or re-purchase decision, and thereby the company's sales. The importance of each requirement is used both as an indicator for which requirements the manufacturer should focus on for improvement purposes, and as an input to the calculation of intangible costs described in Chapter 4.7. The model requires that each requirement only appears once in the QFD matrix. To obtain this, each requirement has been weighted by the manufacturer based on each user group's importance for the purchase or re-purchase decision, and each user group's average attachment of importance to each customer requirement. The overall importance for each customer requirement appears as the sum of the weighted importance from each user group. The approach is described in Table 4.6.

Table 4.6 Weighted Overall Importance for Each Customer Requirement

User Groups	Req	AI = Average Importance	W = Weight	Weighted Importance = AI x W
A	1	AI_{A1}	W_A	$AI_{A1} \times W_A$
	2	AI_{A2}	W_A	$AI_{A2} \times W_A$
	3	AI_{A3}	W_A	$AI_{A3} \times W_A$
	6	AI_{A6}	W_A	$AI_{A6} \times W_A$
	...	...	...	...
B	3	AI_{B3}	W_B	$AI_{B3} \times W_B$
	6	AI_{B6}	W_B	$AI_{B6} \times W_B$
	...	...	...	...
C	1	AI_{C1}	W_C	$AI_{C1} \times W_C$
	6	AI_{C6}	W_C	$AI_{C6} \times W_C$
	7	AI_{C7}	W_C	$AI_{C7} \times W_C$
	9	AI_{C9}	W_C	$AI_{C9} \times W_C$
	...	...	...	...

⇒

Req	From Group	Overall Importance of each Customer Requirement
1	A+C	$AI_{A1} \times W_A + AI_{C1} \times W_C$
2	A	$AI_{A2} \times W_A$
3	A+B	$AI_{A3} \times W_A + AI_{B3} \times W_B$
6	A+B+C	$AI_{A6} \times W_A + AI_{B6} \times W_B + AI_{C6} \times W_C$
7	C	$AI_{C7} \times W_C$
9	C	$AI_{C9} \times W_C$
...	...	...

A numeric example of the use of this approach can be found in Chapter 6.1.5.

4.4 TARGET VALUES AND OPERATIONAL GOALS

4.4.1 Target Values Expressed by the Customer

Target values (❹ in the upper part of Figure 4.1) are indications of how much of a product characteristic the customer wants, his expectations of the characteristic. These target values often indicate the level of performance that prevent dissatisfaction, they do not necessarily reflect optimal performance. For instance, if customers are asked what acceptable waiting time in a line is, they might say three minutes. This only indicates that waiting for three minutes does not lead to dissatisfaction. Reducing this waiting time can, on the other hand, lead to satisfaction, and if it is substantially better than the competitors' it can be considered an attraction, leading to competitive advantages. The important objective is to identify when the customer becomes dissatisfied and when further improvement will not lead to additional customer satisfaction. It serves no purpose to improve performance beyond a certain level if a competitive advantage cannot be achieved. It only incurs costs without additional satisfaction or delight. The target value that is expressed by the customer is used as an input to the loss function monitoring critical external failure costs, customer incurred costs and environmental costs.

In general, metrics of target values fall into three categories (Cohen, 1995); "larger-the-better", "smaller-the-better" and "target-the-best". The example above is a typical "smaller-the-better" metric. Customer requirements will normally be of the type "smaller-the-better" or "larger-the-better", while translated key process parameters will usually be "target-the-best" characteristics.

4.4.2 Operational Goals and Targets

Operational goals and targets (❹ in the lower part of Figure 4.1) are the target values customers expressed for each customer requirement, translated to key process parameters. This measurement scale is used as an input to loss functions used to monitor critical internal PQCs. The scale should be set so the lower limit reflects the point when the customer becomes dissatisfied, and abstain from purchasing the product. The upper limit represents the point where the customer is perfectly satisfied or delighted. These limits determine where shifts in the loss function will occur.

4.5 PERFORMANCE OF KEY PROCESS PARAMETERS

Engineering Competitive Assessment or Technical Benchmarks compare the performance of each key process parameter with the performance of the competitors', and give input to the process efficiency cost element in the PQC model (❺ in Figure 4.1). The number of key process parameters may be considerable, and the most important parameters according to the prioritizing done in the relationship section of the QFD matrix should be emphasized. The correlation matrix or the "roof" of the QFD matrix identifies positive and negative correlation (technical tradeoffs). These tradeoffs are often a result of engineering compromises because of limitations in current processes, and they represent opportunities for improvement (Hofmeister et. al., 1996). These elements should also be included in the benchmarking study.

4.6 PERFORMANCE OF PRODUCT CHARACTERISTICS

The performance of product characteristics (❻ in Figure 4.1) describes how well the manufacturer fulfills each customer requirement compared to their competitors or chief competitor. This part of the QFD matrix is, along with the importance of each requirement, used as an input to monitor intangible PQCs. This information should be obtained by accomplishing surveys of the competitors' customers, which is more comprehensive than surveying own customers. The company's own customers may also have knowledge about competing products, and can be asked to rate the current product or service against the one provided by a competitor. However, own customers are most likely biased towards the company, and their rating of performance may not be reliable.

4.7 COST INDEXES USED TO MONITOR INTANGIBLE COSTS

The purpose of the approach used to estimate intangible costs is to link these costs to actual performance. *This is a new methodology developed to overcome the previous problems with estimating and measuring intangible costs.* The overall costs for the intangible element have to be based on customer surveys and company experience, as shown in Figure 3.2 on page 24. The following elements have to be determined:

① An estimate of the lost revenue of the current product or service because one existing customer is lost. This can be estimated as re-purchase intention and the average number of re-purchases during a given time frame.

② An estimate of how many potential customers that are lost because the dissatisfied customer advises against the current product.

③ An estimate of the portion of loss-of-reputation costs that the product causes. That is, how much will the current product's poor quality influence the customer's purchase decision of other products provided by the manufacturer. This element will strongly depend on the product mix the company provides, and the similarity and coherence between each product. Re-purchase decisions will not be influenced to the same degree since the customer has first hand experience with each product. Loss-of-reputation costs should be estimated for the company as a whole based on their product mix, and then distributed to different products.

The sum of element ①, ②, and ③ has been denoted C_{tot} which is an estimate of the potential loss due to a failure that causes a dissatisfied customer that leaves the company because of poor product or service performance. This total expected loss has been linked to actual process performance through the QFD matrix. The totality of characteristics identified through customer requirements (*Req #1, Req #2, , Req #n*) completely describes the product. A cost index (CI_i - ❼ in Figure 4.4) has been defined as the customer's rating of importance attached to each requirement (I_i - ❸ in Figure 4.4) times the customer's rating of the company's performance compared to the chief competitor' (P_i - ❻ in Figure 4.4). The cost index can be used as an estimator of the probability that poor product or service performance will result in an intangible loss. If the importance is low (I_i=*1*) the probability that a loss will occur is low, but if the importance is high (I_i=9), the probability of losing the customer is high. The performance of the company compared to the chief competitor will also influence the probability of a loss. The difference between the company's and their chief competitor's performance has been denoted P_i, which is a performance index. A negative P_i indicates that the company's performance is better than their chief competitor. If the company's performance is better than the chief competitor's, a loss will most likely *not* occur even if the customer is dissatisfied and the requirement has a high importance attached to it. The customer has no alternative supplier and will not gain anything by leaving the company. If the company's performance is low compared to the chief competitor's, a loss will most likely occur.

The cost of getting new customers as replacement for those who are lost has been considered beyond the scope of a PQC system, and have not been included in the estimate of intangible PQCs. It is normally assumed that this cost is about ten times as high as selling to existing customers, but it would be literally impossible to obtain accurate measures or estimates of these costs.

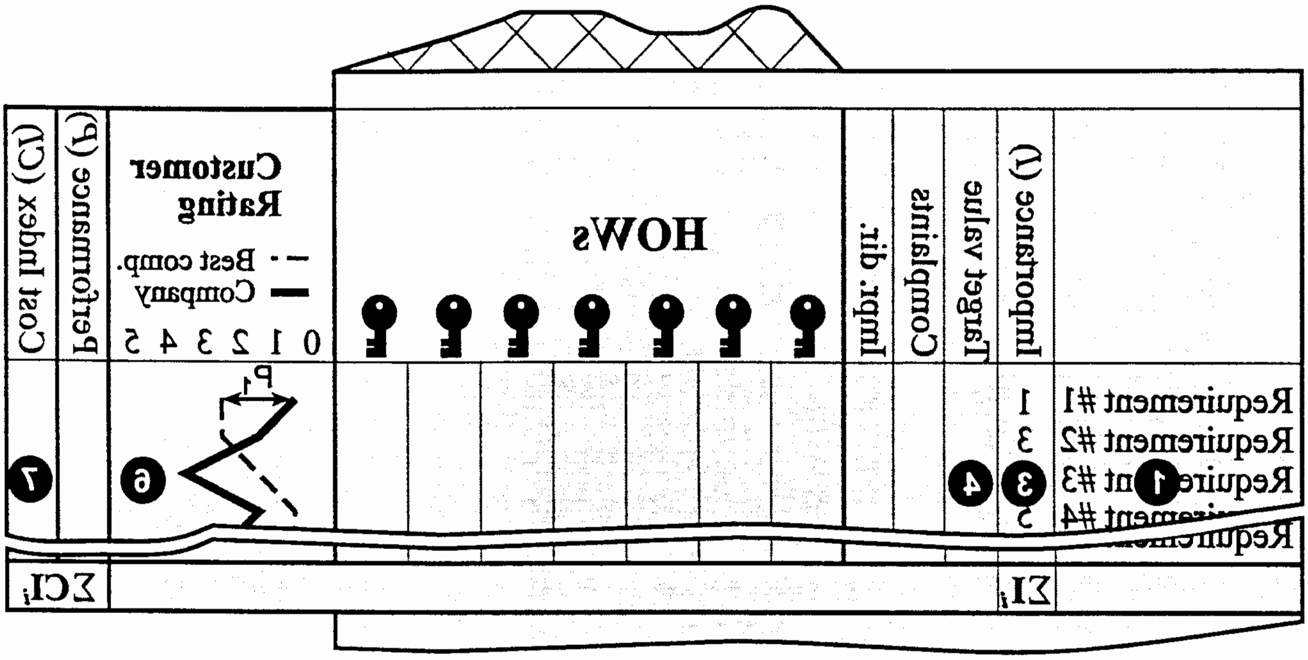


Figure 4.4 Estimating Intangible Costs (Losses)

In the worst case the difference in performance (P_1, P_2, , P_n) can be 5 to the disadvantage of the company for every customer requirement (Req #1, Req #2, , Req #n). This gives the maximum expected loss (C_{tot}), that was estimated in ①, ②, and ③ on the previous page. The cost index (CI, ❼ in Figure 4.4) for each customer requirement can be expressed as:

$$CI_i = I_i \times P_i$$

Where: I_i = Importance attached to requirement i (❷).

P_i = The company's performance for requirement i where a negative P_i indicates better performance than the chief competitor.

CI_i = Cost index for requirement i (❼).

$CI_{i,max} = I_i \times 5$ which equals worst case difference in performance ($P_i = 5$).

A loss factor (f_{loss}) can be described as the overall loss estimated in ①, ②, and ③ (C_{tot}) divided by the worst case cost index (CI_{max}), that is when the difference in performance is five for every requirement to the disadvantage of the company:

$$f_{loss} = \frac{C_{tot}}{CI_{max}} = \frac{C_{tot}}{5 \times \sum_{i=1}^{n} I_i}$$

The expected annual loss for one product can be expressed as the loss factor times the sum of cost indexes (the probability that not meeting each customer requirement will lead to a intangible loss):

$$E(L) = f_{loss} \times \sum_{i=1}^{n} CI_i$$

Where a positive P_i indicates that the performance of the chief competitor is better than the company, and a negative P_i indicates that the company performs better than the chief competitor. Negative values of P_i will per definition not result in a loss ($\div P_i \equiv 0$).

Example:
A product is described by 6 different customer requirements with the attached importance I_1 to I_6. The customer's evaluation of performance is given by P_1 to P_6. The sum of the three cost elements ①, ②, and ③ is C_{tot} = $400, which is the total estimated loss due to one dissatisfied customer that leaves the company as a result of poor product or service performance.

Table 4.7 Customer Incurred Costs - Example

Customer requirement	Importance I_i	Performance P_i	Cost Index $CI_i = I_i \times P_i$
Req #1	1	2	2
Req #2	7	-1	-7 ⇒ 0
Req #3	3	0	0
Req #4	5	-3	-15 ⇒ 0
Req #5	9	2	18
Req #6	2	3	5
Sum	$\Sigma I_i = 27$		$\Sigma CI_i = 25$

$$f_{loss} = \frac{C_{tot}}{CI_{max}} = \frac{C_{tot}}{5 \times \sum_{i=1}^{n} I_i} = \frac{400}{5 \times 27} = 2.96$$

$$E(L) = f_{loss} \times \sum_{i=1}^{n} CI_i = 2.96 \times 25 = \underline{\underline{\$74.00}}$$

This represents the *annual* expected intangible PQC for the specific product. The expected loss (E(L)) has been based on the total loss (C_{tot}) that is expressed as lost revenue due to the loss of this customer ①, lost revenue due to potential customers that refrain from buying the product ②, and lost revenue due to lost sales of other products provided by the company ③. The expected loss result from the total loss (C_{tot}) and the probability that a loss will occur (ΣCI_i), which is determined by the company's performance (P_i) and the customer's stated importance for each requirement (I_i). This approach makes it possible to focus improvement activities to yield maximum benefit for the customer and obtain an optimal reduction of intangible PQCs.

5. THE LOSS FUNCTION

The Taguchi loss function is linked to the definition of quality. If the term quality is used to describe a product (or service), it may mean "conforming to specifications" or "fitness for use" (Roth and Albright, 1994). The "Zero-defect" approach that has been adopted by many western companies is often based on the definition "conformance to specifications", where it is assumed that a product characteristic is equally good within its specification limits. Any variation within these limits is accepted, and loss only occurs when the product characteristic exceeds the limits. On the other hand, Taguchi's approach is based on the interpretation "fitness for use" and the belief that any deviation from the target value of a product characteristic results in a loss to the society. Taguchi based the need for this approach on two conditions (Turner, 1990):

❶ From the customer's view, there is often practically no difference between a product just inside specifications and a product just outside. Conversely, there is a far greater difference in the quality of a product that is on the target and the quality of one that is close to a limit.

❷ As customers get more demanding, there is a pressure to reduce variability. A conventional approach (Figure 5.1) does not recognize this pressure.

Further documentation concerning the use of the Taguchi loss function can be found in Roth and Albright (1994); Margavio, Fink and Margavio (1994); Taguchi (1993); Albright and Roth (1992); Taguchi and Clausing (1990).

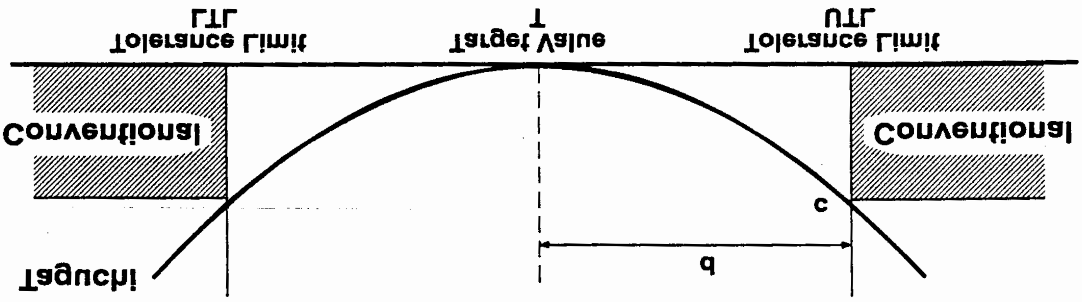


Figure 5.1 Traditional Loss Function versus Taguchi's Loss Function

The symmetric quadratic function is based on a Taylor series expansion about the target value (Taguchi, Elsayed, and Hsiang, 1989) and is merely an approximation of the true form of the loss function. The analytical form of the function is often difficult to determine, but when the required data is available, they should be used (Fathi, 1990). An approach to gather these data has been proposed in section 5.4. The slope of the function is based on estimates of actual loss at the tolerance limits, that is, where the product becomes unfit for use (or when the customer refrains from buying the product). A simple equation describes the loss function for a target-the-best characteristic (Albright and Roth, 1992):

$$L(x) = k(x-T)^2 \quad ① \quad k = \frac{c}{d^2}$$

Where: x = Measured value of characteristic

T = Target value of characteristic

k = Proportionality constant

c = Loss associated with a unit produced at tolerance limit

d = Distance from target value to tolerance limit

Albright and Roth (1992) have demonstrated that the total loss based on the equation for a single unit ① is found by multiplying the average loss by the total number of units, where the average loss per unit can be expressed as:

$$L(x)_{avg} = k\left[\frac{\sum_{i=1}^{n}(x-T)^2}{n}\right] = k(MSD) \quad \text{where: } \begin{array}{l} MSD = \text{mean squared deviation} \\ n = \text{number of units in sample} \end{array}$$

If the mean and standard deviation for the distribution of the characteristic are known, the average loss per unit for a target-the-best characteristic is approximated by the following equation (Tunner, 1990):

$$L(x)_{avg} = k[\sigma^2 + (\mu - T)^2] \quad \text{where: } \begin{array}{l} \sigma = \text{process standard deviation} \\ \mu = \text{process average} \end{array}$$

The loss is made up of two parts, the variance and the relative location of the average of a performance characteristic for a group of products. To minimize the loss to the society, the product characteristic needs to be centered at the target value and the variance of that characteristic has to be reduced.

For a smaller-the-better characteristic the minimum loss $L(x)$ occurs when $x=0$, which is the target value T. The minimum loss for a larger-the-better characteristic occurs when x approaches infinity, leading to an inverted x in the equation. Loss functions for different types of characteristics can be summarized as in Table 5.1 (Ross, 1988).

Table 5.1 Types of Loss Functions

Type of characteristic	Loss for an individual part $L(x)$	Average loss per part in a distribution $L(x)_{avg}$
Larger-the-Better	$k\left(\frac{1}{x^2}\right)$	$k\left[\frac{1}{\mu^2}\right]\left[1+\frac{3\sigma^2}{\mu^2}\right]$
Target-the-Best	$k(x-T)^2$	$k[\sigma^2 + (\mu - T)^2]$
Smaller-the-Better	kx^2	$k[\sigma^2 + \mu^2]$

5.1 PREVIOUS USE OF THE LOSS FUNCTION TO MEASURE QUALITY COSTS

The concept of a continuous quadratic loss function has its roots in statistical decision theory and the theory of economic behavior, where it can be found extensively, but its use in the context of quality is somewhat new (Fathi, 1990). In recent years the loss function has been proposed to monitor external quality costs including a primary component of lost sales (Margavio, Fink, and Margavio, 1994) and intangible quality costs (Kim and Liao, 1994; Albright and Roth, 1992) like customer's dissatisfaction, loss because of bad reputation, and lost market share. The ASQC Quality Cost Committee (1990) has also in general terms advocated the use of the loss function in *Principles of Quality Costs*. Albright and Roth (1992) identify four major areas where the Taguchi loss function can help managers and managerial accountants to improve operations and reduce costs:

❶ The function provides an indication of the magnitude of the hidden quality costs at the same time as it shows that there are costs associated with variability in processes and products even when the products are within specification limits.

❷ It helps evaluate investment proposals for process improvement by visualizing the cash savings that result from reducing the variability of the process output.

❸ Loss functions help measure actual performance of process improvement projects.

❹ The function can be used to evaluate progress towards quality goals of reducing customer dissatisfaction based on the assumption that quality is best and costs are lowest when product characteristics are on target.

Although the Taguchi loss function has been proposed to measure quality costs, little have been done to describe how to determine the magnitude of the loss at the tolerance limit (c) and the distance from the target value to this limit (*d*) (Figure 5.1). These values are critical for determining the proportionality constant (*k*) and thereby the overall validity of the loss function. The literature emphasizes that these values have to be estimated, but a good methodology has not been provided.

5.2 CONSTRUCTING LOSS FUNCTIONS

Poor quality costs as a result of key process parameter's deviations from the target value have been measured by Taguchi's loss function. To determine the exact shape of the loss function would have required a substantial amount of survey data and would not have been practical or economically feasible to accomplish. The loss functions have instead been constructed based on calculations of losses at specific points where the performance of the characteristic changes. A quadratic function has been used between each point leading to loss functions that are asymmetric with different sensitivity in different regions. The approach is slightly different based on the type of characteristic; target-the-best, smaller-the-better, or larger-the-better.

5.2.1 Target-the-Best Characteristics

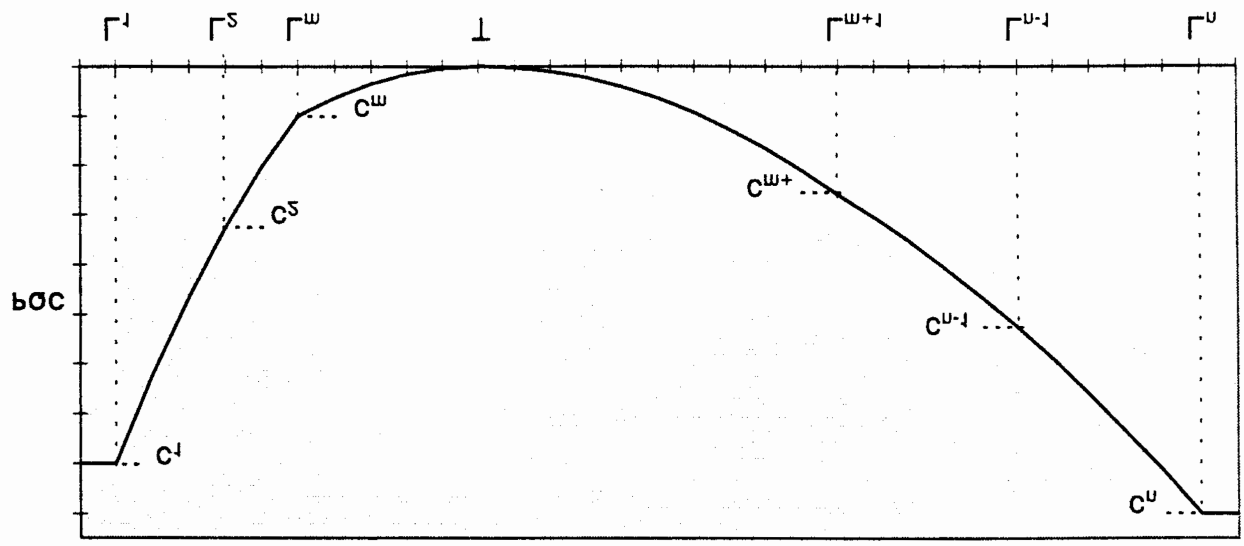


Figure 5.2 Loss Function for Target-the-Best Characteristics

The loss function for a target-the-best characteristic is described by the following equations (partly based on Kim and Liao, 1994):

$$
L(x)=\begin{cases}
c_1 & -\infty < x \le L_1 \\
k_1[(T-x)^2-(1-\alpha_1)(T-L_2)^2] & L_1 \le x \le L_2 \\
\ldots\ldots & \ldots\ldots \\
k_{m-1}[(T-x)^2-(1-\alpha_{m-1})(T-L_m)^2] & L_{m-1} \le x \le L_m \\
k_{m-1}\alpha_{m-1}(T-x)^2 & L_m \le x \le T \\
k_m\alpha_m(x-T)^2 & T \le x \le L_{m+1} \\
k_m[(x-T)^2-(1-\alpha_m)(L_{m+1}-T)^2] & L_{m+1} \le x \le L_{m+2} \\
\ldots\ldots & \ldots\ldots \\
k_{n-2}[(x-T)^2-(1-\alpha_{n-2})(L_{n-1}-T)^2] & L_{n-1} \le x \le L_n \\
c_n & L_n \le x \le \infty
\end{cases}
$$

Where:

n = Number of regions between L_1 and L_n. (total number of regions)

m = Number of regions between L_1 and the target value T

T = Target value for key process parameter

L_1 - L_n = Limits where performance of key process parameter change

c_1 - c_n = Estimated loss at limits L_1 - L_n

$$
k_p = \frac{c_p - c_{p+1}}{(T-L_p)^2-(T-L_{p+1})^2}\Bigg|_{p=1}^{m-1} \qquad k_p = \frac{c_{p+2} - c_{p+1}}{(L_{p+2}-T)^2-(L_{p+1}-T)^2}\Bigg|_{p=m}^{n-2}
$$

$$
\alpha_p = \frac{(c_p - c_{p+1})(T-L_{p+1})^2}{c_{p+1}[(T-L_p)^2-(T-L_{p+1})^2]}\Bigg|_{p=1}^{m-1} \qquad \alpha_p = \frac{(c_{p+2} - c_{p+1})(L_{p+1}-T)^2}{c_{p+1}[(L_{p+2}-T)^2-(L_{p+1}-T)^2]}\Bigg|_{p=m}^{n-2}
$$

k_1 to k_{n-2} are proportionality constants and α_1 to α_{n-2} are adjustment constants used to obtain a smooth transition between each region of the loss function. These formulas have been derived as follow:

$$c_2 = \alpha_1 k_1 (T-L_2) \text{ and}$$

$$c_1 = k_1[(T-L_1)^2-(1-\alpha_1)(T-L_2)^2 = k_1[(T-L_1)^2-(T-L_2)^2]+c_2$$

$$\Rightarrow k_1 = \frac{c_1-c_2}{(T-L_1)^2-(T-L_2)^2} \quad \text{and} \quad \alpha_1 = \frac{c_2}{k_1(T-L_2)} = \frac{c_2[(T-L_1)^2-(T-L_2)^2]}{(c_1-c_2)(T-L_2)^2}$$

The same approach applies for k_2 to k_{n-2} and α_2 to α_{n-2}.

5.2.2 Smaller-the-Better Characteristics

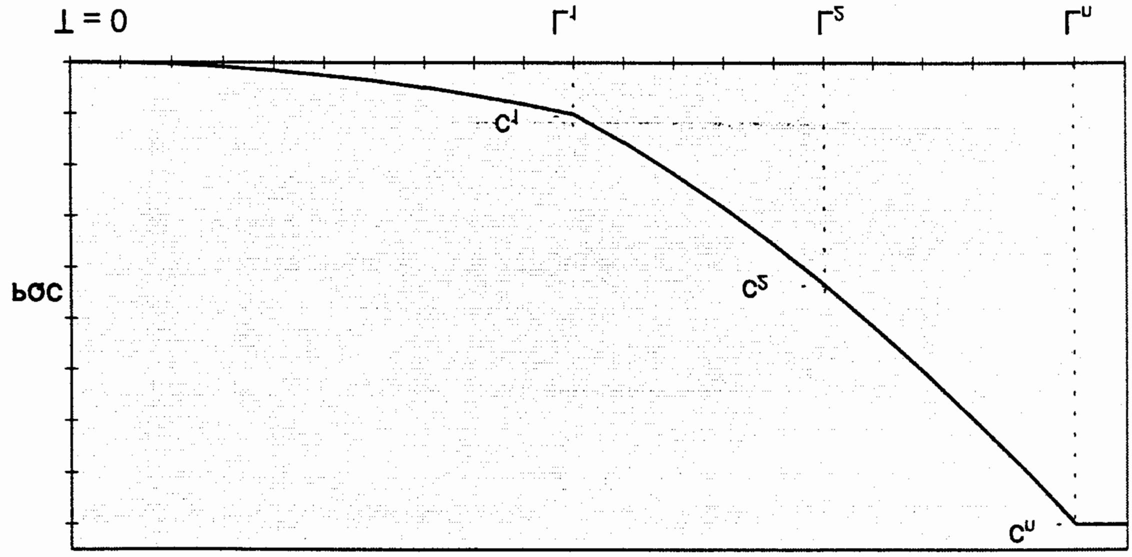


Figure 5.3 Loss Function for Smaller-the-Better Characteristics

A loss function for a smaller-the-better characteristic is similar to the target-the-best situation when the target value T=0. This gives the following equations for the loss function:

$$L(x)=\begin{cases} a_1 k_1 x^2 & \text{for } 0 \le x \le L_1 \\ k_1[x^2-(1-a_1)L_1^2] & \text{for } L_1 \le x \le L_2 \\ \ldots\ldots & \ldots\ldots \\ k_{n-1}\left[x^2-(1-a_{n-1})L_{n-1}^2\right] & \text{for } L_{n-1} \le x \le L_n \end{cases}$$

Where: $\left. k_p = \dfrac{c_{p+2}-c_{p+1}}{L_{p+2}^2-L_{p+1}^2} \right|_{p=1}^{n-1}$ and $\left. a_p = \dfrac{c_{p+1}(L_{p+2}^2-L_{p+1}^2)}{(c_{p+2}-c_{p+1})L_{p+1}^2} \right|_{p=1}^{n-1}$

5.2.3 Larger-the-Better Characteristics

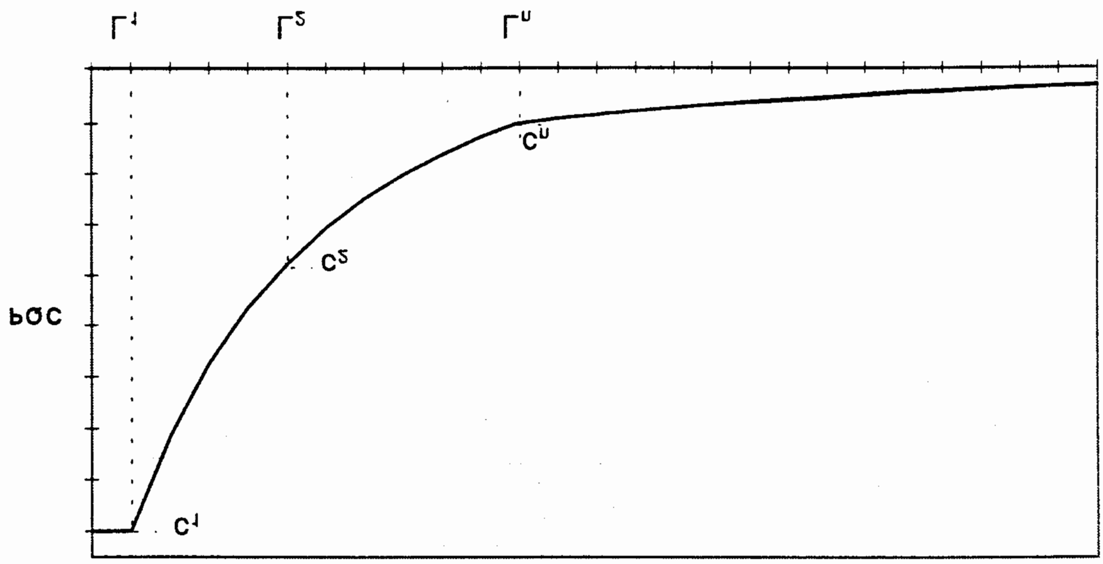


Figure 5.4 Loss Function for Larger-the-Better Characteristic

A larger-the-better characteristic reaches the minimum loss when y approaches infinity, which renders a zero loss impossible in a production environment. L_1 in Figure 5.4 is the lower tolerance limit and L_n is the target value used in production. Based on the equation in Table 5.1, the loss function can be described as:

$$L(x)=\begin{cases} k_1\left[\dfrac{1}{x^2}-\dfrac{1-\alpha_1}{L_2^2}\right] & \text{for } L_1 \le x \le L_2 \\ \ldots\ldots & \\ k_{n-1}\left[\dfrac{1}{x^2}-\dfrac{1-\alpha_{n-1}}{L_n^2}\right] & \text{for } L_{n-1} \le x \le L_n \\ \alpha_{n-1}k_{n-1}\left[\dfrac{1}{x^2}\right] & \text{for } L_n \le x \le \infty \end{cases}$$

Where

$$k_p = \left.\frac{c_p - c_{p+1}}{\dfrac{1}{L_p^2}-\dfrac{1}{L_{p+1}^2}}\right|_{p=1}^{n-1} \quad \text{and} \quad \alpha_p = \left.\frac{\dfrac{(c_p - c_{p+1})}{L_{p+1}^2}}{c_{p+1}\left[\dfrac{1}{L_p^2}-\dfrac{1}{L_{p+1}^2}\right]}\right|_{p=1}^{n-1}$$

Common for all types of characteristics is that the function becomes a more exact representation of the actual loss as the number of intervals increases. The number of intervals should be based on a cost-benefit analysis, but in most cases it is evidently based on change in performance. For instance, for internal failure costs a shift will occur when a product has to be reworked, an another shift when it has to be scraped. Equivalent shifts in performance will occur for external failure costs, customer incurred costs, and environmental costs. The purpose is to identify when the performance changes, and the financial result of the change. A loss function with four to six intervals will normally represent a sufficiently accurate estimate of the loss. The benefit of a more accurate analysis will suffer under the costs of obtaining additional information.

5.2.4 Construction of an Overall Loss Function for Each Customer Requirement

To obtain a linkage between individual customer requirements and losses due to poor product performance, the losses for critical internal failure costs have been transferred from the key process parameter level to the customer requirement level. One customer requirement may be influenced by several individual key process parameters. Loss functions for external failure costs, customer incurred costs, and environmental costs are based directly on customer requirements. The overall loss for not meeting one customer requirement adequately has been determined through three steps (Figure 5.6, page 55):

❶ For critical internal failure costs, individual loss functions $L_{Ifi,1}(x)$, $L_{Ifi,2}(x)$, .., $L_{Ifi,n}(x)$ have been constructed for each key process parameter 1,..,n, that influences the fulfillment of a specific customer requirement. Loss functions for critical external failure costs $L_{Efi}(x)$, customer incurred costs $L_{Ci}(x)$, and environmental costs $L_{Eni}(x)$ have been based directly on each customer requirement. Loss functions are based on the equations provided in 5.2.1, 5.2.2, and 5.2.3. Necessary data have been gathered based on the approach described in Chapter 5.4, page 58. The performance of each key process parameter or the fulfillment of each customer requirement has been determined based on the probability that a failure will occur. The probability distributions $g_{if,1}(x)$, $g_{if,2}(x)$, ..., $g_{if,n}(x)$, $g_{Ef}(x)$, $g_{Ci}(x)$, and $g_{En}(x)$ have to be determine in each situation. Key process parameters will normally be represented by target-the-best characteristics, where a normal distribution has been assumed. This assumption cannot be done for the other cost elements, which will normally be of the form smaller-the-better or larger-the-better. The expected loss, $E(L)$, can be illustrated as the area between the loss function $L(x)$ and the appurtenant probability distribution $g(x)$, visualized as the shaded area in Figure 5.7, page 56. A detailed description of the approach can be found in Chapter 5.3.1.

❷ For critical internal failure costs, the x-scale of the loss function for each key process parameter has been normalized between -1 and +1 to transfer each function to the same basis. The normalization has been based on tolerance limits for each key process parameter, where the lower tolerance limit corresponds to -1 and the upper to +1 (Figure 5.5). The overall loss due to not meeting the customer requirement has been obtained as the sums of each loss function time the average monthly occurrence of failures for each key process parameter (weight):

$$L_{if}(x)=L_{if,1}(x) \text{ x } Weight(1)+L_{if,2}(x) \text{ x } Weight(2)+, ...,+L_{if,n}(x) \text{ x } Weight(n).$$

If key process parameters have been identified correctly, they should be independent, and the overall performance of how the customer requirement is met can been determined as the product of each probability distribution:

$$g_{if}(x)=g_{if,1}(x) \text{ x } g_{if,2}(x)\text{x } ... \text{ x } g_{if,n}(x),$$

and the expected internal failure cost for the customer requirement, $E(L_{if})$ can be visualized as the area beneath $L_{if}(x)$ and $g_{if}(x)$ in Figure 5.6.

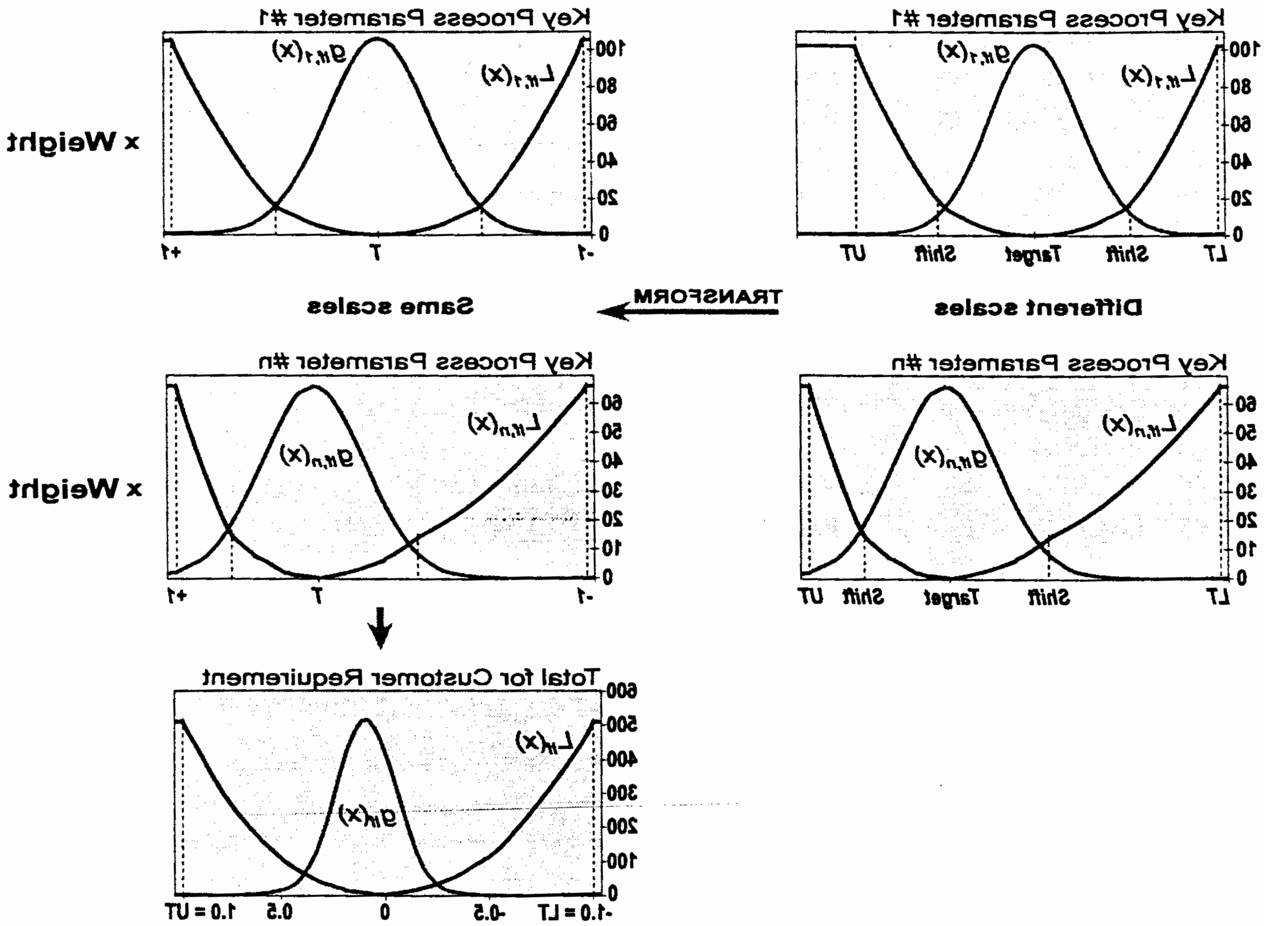
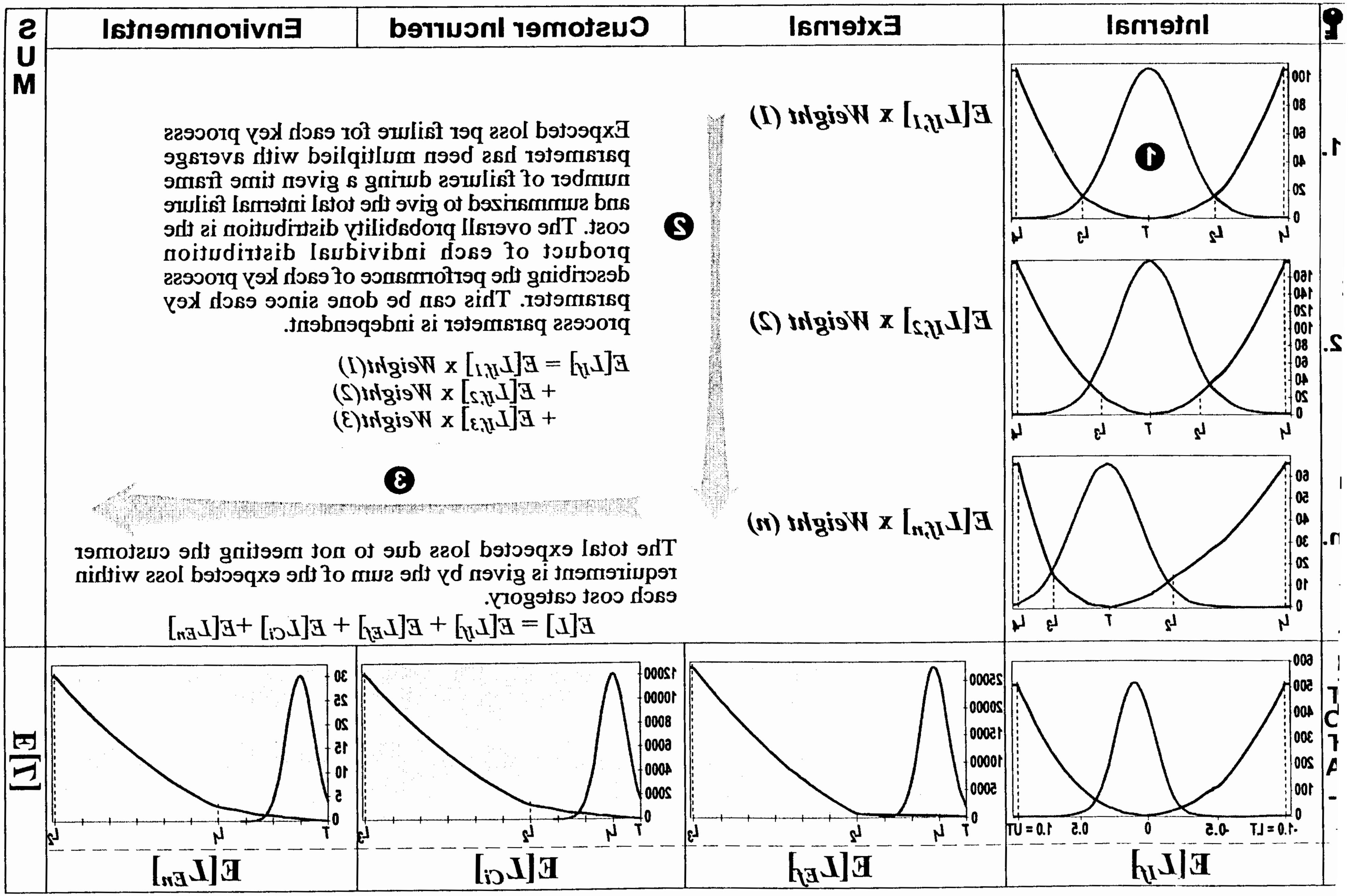


Figure 5.5 *Loss for Internal Failure Costs Based on Each Key Process Parameter*

❸ The overall expected loss for one customer requirement during a given time frame, E(L), have been calculated as the sum of the loss for each cost element that was obtained in step ❶ and ❷. $E(L)=E(L_{if})+E(L_{ef})+E(L_{ci})+E(L_{en})$.

Figure 5.6 on page 55 demonstrates the approach. The customer requirement is described by a smaller-the-better characteristic, while each key process parameter that influences the fulfillment of the customer requirement is described by target-the-best characteristics. There are three key process parameters that affect the fulfillment of the customer requirement, and the loss function for each key process parameter has been summarized to obtain an overall loss function for internal failure costs. The performance of each key process parameter, represented by their probability distribution, has been multiplied to get an overall performance of how the customer requirement is met. External failure costs, customer incurred costs, and environmental costs have been based directly on the customer requirement. Tolerance limits for internal failure costs have been determined based on production specifications, while the other cost elements are based on the customer's perception of what is acceptable performance. Shifts in loss functions are based on shifts in performance of the key process parameter or the fulfillment of the customer requirement. The result is an expected PQC for each cost element and an overall sum for the customer requirement. Each cost element is the same that can be found in Figure 3.2 on page 24.


Internal
External
Customer Incurred
Environmental
1.
2.
n.
TOTAL
SUM
$E[L_{If,1}]$ x Weight (1)
$E[L_{If,2}]$ x Weight (2)
$E[L_{If,n}]$ x Weight (n)
Expected loss per failure for each key process parameter has been multiplied with average number of failures during a given time frame and summarized to give the total internal failure cost. The overall probability distribution is the product of each individual distribution describing the performance of each key process parameter. This can be done since each key process parameter is independent.
$E[L_{If}] = E[L_{If,1}]$ x Weight(1) + $E[L_{If,2}]$ x Weight(2) + $E[L_{If,3}]$ x Weight(3)
The total expected loss due to not meeting the customer requirement is given by the sum of the expected loss within each cost category.
$E[L] = E[L_{If}] + E[L_{Ef}] + E[L_{Ci}] + E[L_{En}]$
$E[L_{If}]$
$E[L_{Ef}]$
$E[L_{Ci}]$
$E[L_{En}]$
$E[L]$

5.3 ESTIMATING THE ACTUAL LOSS FOR EACH CUSTOMER REQUIREMENT

5.3.1 Loss for Each Key Process Parameter

The expected loss for one customer requirement has been calculated based on the overall loss function for each key process parameter $L_1(x)$, $L_2(x)$, .. , $L_n(x)$ and their expected probability distribution. If the actual probability distribution is unknown, a normal distribution has been assumed for a process under statistical control. The mean value ($\bar{x}$) and the estimate of the variance (s_x^2) have been determined based on samples of performance for each key process parameter and are used as estimates of μ and σ^2. The expected loss can be illustrated as the area under the probability distribution $g_1(x)$ and the loss function $L_1(x)$ as the shaded area in Figure 5.7.

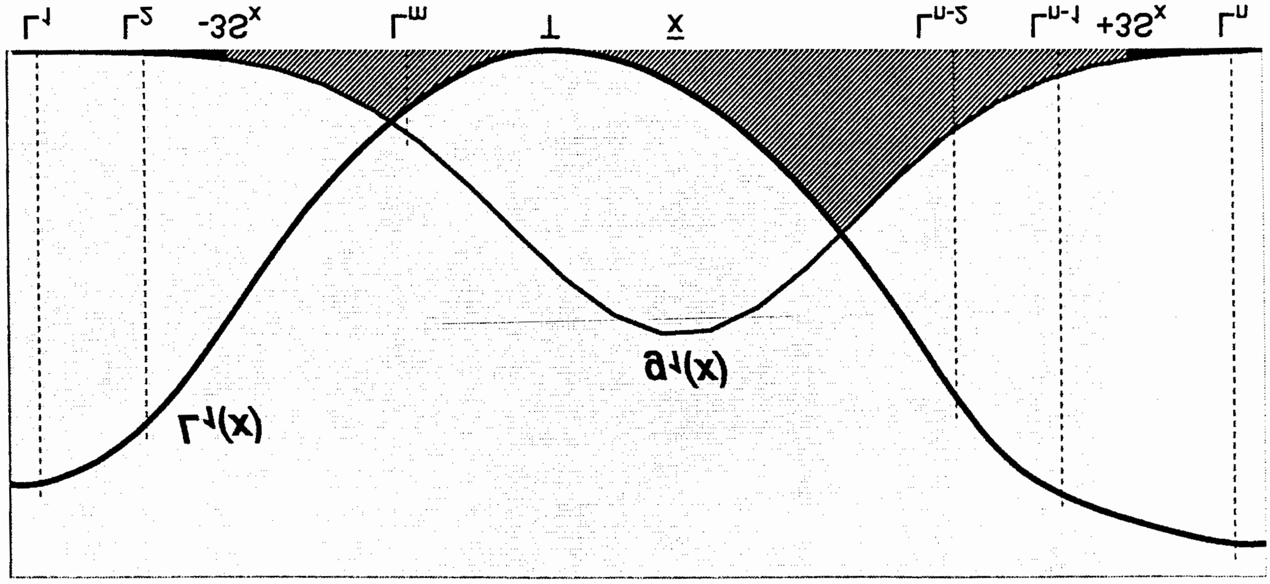


Figure 5.7 Determine the Expected Loss for One Key Process Parameter

For a target-the-best characteristic the expected loss at one discreet value of x can be found as the loss $L_1(x)$ multiplied by the probability distribution $g_1(x)$, where:

$$L_1(x)=\begin{cases} c_1 & -\infty < x \le L_1 \\ k_1[(T-x)^2-(1-a_1)(T-L_2)^2] & L_1 \le x \le L_2 \\ \cdots\cdots & \cdots\cdots \\ k_{m-1}[(T-x)^2-(1-a_{m-1})(T-L_m)^2] & L_{m-1} \le x \le L_m \\ k_{m-1}a_{m-1}(T-x)^2 & L_m \le x \le T \\ k_m a_m (x-T)^2 & T \le x \le L_{m+1} \\ k_m[(x-T)^2-(1-a_m)(L_{m+1}-T)^2] & L_{m+1} \le x \le L_{m+2} \\ \cdots\cdots & \cdots\cdots \\ k_{n-2}[(x-T)^2-(1-a_{n-2})(L_{n-1}-T)^2] & L_{n-1} \le x \le L_n \\ c_n & L_n \le x \le \infty \end{cases}$$

n = number of regions between L_1 and L_n.

m = number of regions between L_1 and the target value T, and

$$g_1(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} = N(\mu, \sigma^2)$$

The overall expected loss for one key process parameter can then be calculated as the integral of $L_1(x)$ multiplied by the probability distribution $g_1(x)$ between minus infinity and plus infinity.

$$E[\overline{L_1}] = \int_{-\infty}^{\infty} L_1(x) g_1(x) dx \qquad \text{where } g_1(x) \text{ is } N(\mu, \sigma^2)$$

For all practical purposes the expected loss has been integrated between $\mu \pm 3\sigma$, giving the following equation based on Figure 5.7:

$$E[\overline{L_1}] = \int_{-3\sigma}^{L_m} L_1(x) g_1(x) dx + \int_{L_m}^{T} L_1(x) g_1(x) dx + \int_{T}^{L_{n-2}} L_1(x) g_1(x) dx + \int_{L_{n-2}}^{L_{n-1}} L_1(x) g_1(x) dx + \int_{L_{n-1}}^{+3\sigma} L_1(x) g_1(x) dx$$

Where μ-3σ<L_m and μ+3σ>L_{n-1}. The exact solution within each interval has been found by using the standard normal distribution and substituting $(z\sigma+\mu)$ for x. The shaded area in Figure 5.7 can be expressed as:

$$E[\overline{L_1}] = \int_{\mu-3\sigma^*}^{L_m^*} k_{m-1}\left[(T - z\sigma - \mu)^2 - b_{m-1}\right] g(z) dz \quad + \int_{L_m^*}^{T^*} k_{m-1} a_{m-1}\left[(T - z\sigma - \mu)^2\right] g(z) dz$$

$$+ \int_{T^*}^{L_{n-2}^*} k_m a_m\left[(z\sigma + \mu - T)^2\right] g(z) dz \quad + \int_{L_{n-2}^*}^{L_{n-1}^*} k_m\left[(z\sigma + \mu - T)^2 - b_m\right] g(z) dz$$

$$+ \int_{L_{n-1}^*}^{\mu+3\sigma^*} k_{n-2}\left[(z\sigma + \mu - T)^2 - b_{n-2}\right] g(z) dz \qquad \text{Where } g(z) = N(0,1)$$

For one interval L_{m-1}^* to L_m^* the solution of the integral can be expressed as:

$$= \int_{L_{m-1}^*}^{L_m^*} k_{m-1}\left[((T-\mu)^2 - b_{m-1}) - 2(T-\mu)\sigma z + \sigma^2 z^2\right] g(z) dz$$

$$= k_{m-1}\left[(T-\mu)^2 - b_{m-1}\right]\left[G(z)\right]_{L_{m-1}^*}^{L_m^*} + k_{m-1}(T-\mu)\sigma\frac{\sqrt{2}}{\sqrt{\pi}}\left[e^{-\frac{1}{2}z^2}\right]_{L_{m-1}^*}^{L_m^*}$$

$$+ k_{m-1}\sigma^2\frac{1}{\sqrt{2\pi}}\left[-ze^{-\frac{1}{2}z^2} + \sqrt{2\pi}G(z)\right]_{L_{m-1}^*}^{L_m^*}$$

Where: $L_m{}^* = \dfrac{L_m - \mu}{\sigma}$ and $\quad L_{m-1}{}^* = \dfrac{L_{m-1} - \mu}{\sigma}$

$b_{m-1} = (1 - a_{m-1})(T - L_m)^2$ is a constant within each interval.

$G(z)$ is the area from minus infinity to z for the $N(0,1)$ distribution.

The only difference from each region of the loss function is the constant b, k, and a. The solution to the overall integral including every region of the loss function has been obtained through a Microsoft Excel function that is described in Appendix G, on page 125.

The same basic approach applies for a smaller-the-better and a larger-the-better characteristic, but a normal distribution cannot be assumed. For instance, for a larger-the-better characteristic, which typically applies in life testing and reliability, an exponential distribution or a weibull distribution would be expected. The solution of the integral:

$$E[L] = \int_{-\infty}^{\infty} L(x)g(x)dx$$

would have to be obtained through numerical integration like the Simpson approximation (Davis and Rabinowitz, 1967). The expected distribution has to be determined in each case based on the type of characteristic and the obtained data sample.

5.4 GATHERING DATA FOR LOSS FUNCTIONS

5.4.1 Cost Data

The model requires data from an operational Activity Based Costing (ABC) system as input. Kodak, who participated in the case study described in Chapter 6, did not have an ABC system, so necessary cost data for the loss function have been gathered based on a simplified Activity Based Costing (ABC) approach and a simple process analysis. The core purpose has been to make the data gathering as easy as possible to minimize the company's time and resource consumption, and still retain enough accuracy to construct each function. One standardized form (Figure 5.8) has been used to collect all data based on a breakdown of each customer requirement into manageable and measurable activities. These activities have subsequently been added up to an overall cost per failure that has been distributed through cost drivers (Chapter 3.1.2).

Customer requirement: ______________________________

Cost category: ☐ Internal Failure ☐ External Failure ☐ Customer Incurred ☐ Environmental

Key process parameter: ________________ (Only for Internal Failure Costs)

Type of characteristic: ☐ Smaller-the-better ☐ Target-the-best ☐ Larger-the-better

Performance; Satisfied: ________
Shift: ________
Shift: ________
Dissatisfied: ________

Failure/non-conformance: 1: ________
2: ________
3: ________
4: ________

Cost driver: ________

CONSEQUENCES:

ACTIVITIES	COST ELEMENTS																
	Labor				Material				Process				Facility				Total for
	Direct		Indirect		Direct		Indirect		Direct		Indirect		Direct		Indirect		Cost Dr.
	Who	Time	Who	Time	What	Vol.	What	Vol.	Which	Time	Which	Time	Which	Area	Which	Area	
1.																	
2.																	
3.																	
4.																	
5.																	
6.																	

Labor Cost: **Material Cost:** **Process Cost:** **Facility Cost:**

Figure 5.8 Form used to Gather Cost Data

One form summarizes data necessary to construct one loss function, which requires one form for each key process parameter for internal failure costs, and one form for each customer requirement for external, customer incurred, and environmental costs (Figure 5.6, page 55). Key process parameters are not applicable for the three latter cost elements. Performance is based on how the key process parameter meets internal requirements or how customer expectations are met for the customer requirement. Satisfied indicates that there is nothing to gain by further improvement, while a shift in performance occurs when additional activities have to be performed to meet requirements. This might be rework done by the manufacturer or additional service operations done by the customer. Dissatisfaction implies that the key process parameter no longer meets its functional requirement or that the customer requirement is so unsatisfactory met that the product can no longer be used. Failures and non-conformance are the causes that lead to reduced performance of key process parameters or lack of fulfillment of customer requirements.

Consequences are measured by activities that have to be undertaken as a result of a failure or non-conformance. Each failure or non-conformance requires a number of activities that are measured by:

- Labor costs, where direct represents the individuals that accomplish the activity, and indirect represents time spent by those that are affected by the activity (waiting). The total labor cost is determined by who is involved, for how long, and their salary.
- Material costs represent materials that are lost due to the failure. Total costs are driven by type, volume, and unit cost.
- Process costs represent costs of running a process. If rework has to be done, or the process is down because of a failure, process costs occur due to lost capacity.
- Facility Costs represent the cost of the space of the process. If a process is down, there will be no output to pay for the facility, and these costs have to be included in the failure cost.

Costs are driven by activities that consume resources where the overall cost driver has been used to determine the loss at each shift in the loss function (c in Figure 5.1). The application of the approach can be found in Chapter 6.3 and completed forms in Appendix F.

5.4.2 Performance Data

Performance data which are necessary to integrate the loss function, to obtain an expected loss per cost element, should preferably be gathered by measuring each key process parameter or the fulfillment of each customer requirement over time. If this is impossible, as it was at Kodak, failure reports (Appendix A) and customer complaint records (Appendix B) can be used to make estimates. The expected value μ for the performance of key process parameters can be estimated as the number of failures for one year (or more) transferred to a monthly basis, and the standard deviation σ as the variation between each month. The fulfillment of customer requirements has to be estimated based on customer complaints or failure records maintained by the customer. The approach is the same as for key process parameters.

An implementation of the PQC model would require more thorough measures of performance, especially to determine which statistical distribution that best describes the performance. A normal distribution can only be assumed for target-the-best characteristics. Most customer requirements are reliability characteristics of the type smaller-the-better or larger-the-better, and a weibull or exponential distribution should be expected. This has to be determined for each application of the loss function.

5.5 INTERPRETATION OF DATA

5.5.1 Minimizing PQC Through Optimizing Key Process Parameter Tolerances

The use of tolerance design is a natural continuation of the new PQC model. When those key process parameters that have the strongest influence on meeting customer requirement have been identified, they have to be improved. Tolerance design is an engineering technique that optimizes production tolerances based on a minimization of total manufacturer and customer costs (losses). A complete description of tolerance design is beyond the scope of this text, but good descriptions of the approach can be found in literature like Creviling (1997), Fowlkes and Creviling (1995), Clausing (1994), Taguchi (1993), Barker (1990), and Taguchi, Elsayed, and Hsiang (1989). A brief description has been provided in this text to demonstrate the connection between tolerance design and the new PQC model.

Customer tolerances (or high level tolerances) are defined as the deviation from the target value of a product characteristic that will make the customer abstain from buying the product, or as when a significant number of customers take economic action because of off-target performance. This is normally the same as the functional limits of the product (the product will not work if a characteristic exceeds these limits). Producer tolerances (or low level tolerances) on the other hand are tolerance specifications related to component variation control. They are established by the engineering team to minimize the overall loss for the customer and the manufacturer. Producer tolerances are usually much tighter than the customer tolerances because it is normally considerably cheaper to resolve a problem before it reaches the customer. Customer tolerances are often based on the LD50 point, the point at which the probability of failure (or a characteristic falling outside functional limits) is 50%, that is, 50% of the customers become so dissatisfied with the product that they are forced to take economic action. Specification of producer tolerances should be based on the trade-off between the average financial loss due to unacceptable performance and the average cost of producing products with acceptable performance. Quality problems have to be corrected where the corresponding loss exceeds the cost of corrective action. Taguchi (1993) has described the following relationship between customer and producer tolerances:

$$d_T = \frac{d}{\phi}$$

where:
d = functional limit of the product (customer tolerances)
d_T = corresponding tolerance specifications (producer tolerances)
ϕ = economical safety factor

$$\phi = \sqrt{\frac{\text{Average loss when product characteristic exceeds functional limits (external)}}{\text{Average loss when characteristic exceeds production specifications (internal)}}} = \sqrt{\frac{c}{c_T}}$$

Example (Taguchi, 1993): The functional limits of the output voltage of an electric power supply are ± 25% (*d*), where the average loss of such a product being shipped is $300 (c). However, if the voltage of the power supply is just beyond these functional limits (customer tolerances), it can be adjusted at the cost of $1 ($c_T$). The economic safety factor will be:

$$\phi = \sqrt{\frac{c}{c_T}} = \sqrt{\frac{300}{1}} = 17.3$$

To minimize the overall cost, the producer tolerance specification should be set to:

$d_T = \frac{d}{\phi} = \frac{25\%}{17.3} = 1.45\%$, that is much tighter than the functional specification of 25%.

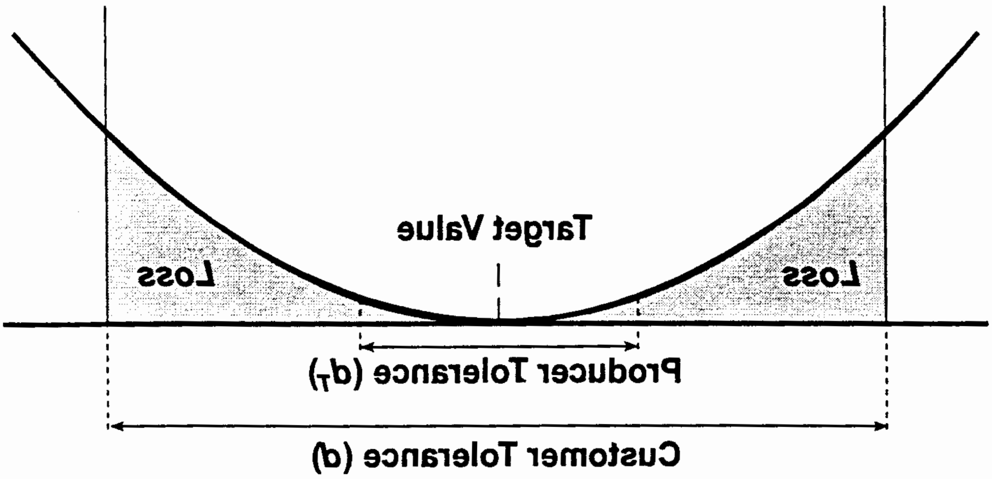


Figure 5.9 Producer Tolerance versus Customer Tolerance

This approach applies for target-the-best and smaller-the-better type characteristics. For larger-the-better type characteristics the effect of the economical safety factor is inverted because the loss is infinite at ϕ instead of having zero value. The equation becomes:

$$d_T = d\phi \qquad \text{and} \qquad L(x)_{avg} \equiv \frac{cd^2}{x^2} \qquad \text{because when} \qquad x \to \infty,\ L(x) \to 0.$$

The described approach links the loss function for one customer requirement to the allowable manufacturing deviation from the target value for one key process parameter. Usually more than one key process parameter influences each customer requirement and Taguchi, Elsayed, and Hsiang (1989) state: *"when a product consist of k components, the characteristics of the product are affected by the tolerances of these components, and tolerance design for each component is needed so that the output characteristic of the product conforms to the functional limit"*. When a customer requirement is influenced by several key process parameters that have a linear relationship with the requirement, the relationship for a single component x can be described as (Creviling, 1997):

$$x = T + \beta(x_0 - T_0) \qquad ②$$

Where:
- x = Actual output response of the customer requirement
- T = The target value for x
- x_0 = Key process parameter that has a linear effect on the customer requirement
- T_0 = Target value for x_0
- β = A factor expressing the linearity between x_0 and x $\left(\beta = \frac{x}{x_0}\right)$

The loss function for a target-the-best customer requirement is given by $L(x) = k(x - T)^2$, where $k = \frac{c}{d^2}$ (equation ① on page 47). The effect one key process parameter has on the overall loss can be found by substituting equation ② into the loss function for the customer requirement (①): $L(x) = k\left[\beta(x_0 - T_0)\right]^2$. This is the same as the loss that occurs when the key process parameter exceeds production specifications (c_T). The tolerance specification for one key process parameter is given by solving the equation $c_T = \frac{c}{d^2}\left[\beta(x_0 - T_0)\right]^2$ for x_0:

$$x_0 = T_0 \pm \sqrt{\frac{c_T}{c}} \times \frac{d}{\beta}.$$

When a customer requirement is influenced by several key process parameters, as described in Chapter 5.2.4, each key process parameter will have a specific linear coefficient β, based on its influence on the fulfillment of the customer requirement. Further descriptions of how to optimize manufacturing tolerances to minimize the overall loss can be found in Creveling, (1997). Creveling also describes how tolerances are optimized when there exists a non-linear relationship between each key process parameter and the customer requirement.

Tolerance design has not been further pursued in this text, and it has not been used to optimize key process parameters identified in the case study described in Chapter 6. The brief overview has been provided to justify that tolerance design is a natural continuation of PQC measurement and an appropriate approach to minimize the overall PQCs. The next chapter describes a case study accomplished to test and verify each element in the new customer and process focused PQC model, as described in Chapter 4 and Chapter 5.

6. CASE STUDY

The testing and verification of the new customer and process focused PQC model is based on a case study at Eastman Kodak Company Equipment & Screen Systems, S&W X-ray, and Strong Memorial Hospital. Kodak is the manufacturer and supplier of products and services to Strong Memorial Hospital and S&W X-ray, while S&W X-ray is a dealer supplying products from Kodak and other manufacturers to hospitals and physicians.

The study was done at one of Eastman Kodak Company's divisions, Equipment & Screen Systems, which is a subdivision of Health Imaging. In 1995 Eastman Kodak Company employed 96,600 people world wide, with $14,980 million in sales and net earnings of $1,252 million. Their headquarters are located in Rochester, New York, along with their main production facilities employing about 45,000 people.

Kodak established their quality cost systems in 1994 when Mr. Fisher became CEO, as a part of his focus on reduction in defect rates and cycle time. Kodak has eight teams responsible for the development of the quality cost system, and the reporting of quality costs on corporate level. Equipment & Screen Systems is the division that has the most mature quality cost systems, which is why it was chosen for the case study. They are certified based on ISO 9001.

Health Imaging is an old division of Kodak established in 1896. Their main products are processing equipment for x-ray films, medical laser printers, mammography products, and x-ray films. Equipment & Screen Systems has been in the market since the late 1950s. Their main products are x-ray film processing equipment, but they also produce ID cameras used to expose name and number on x-ray film, and x-ray equipment for industrial use. The case study is based on a x-ray film processor, model 180LP. This product was chosen because it is relatively new and at the start of its marketable lifecycle.

Equipment & Screen Systems is mainly an assembly plant that receives components from internal and external suppliers. They produce 19 different models, ranging from high capacity equipment used at intensive care units at large hospitals, to simpler units used by general practitioners. In the US, products are sold through dealers to professional customers in a competitive market.

6.1 ACQUISITION AND ANALYSIS OF CUSTOMER DATA

6.1.1 Customers and Main Customer Groups

The 180LP processor is a high volume unit that has to be connected to a laser printer. The setup is quite extensive, restricting the customers to large hospitals, which is one main customer group. Since the case study was limited to one local hospital, other markets have not been considered. The other main customer group that was identified was dealers. They install and maintain the product and are in direct touch with the hospital and the end users. Large hospitals and dealers were the only main customer groups identified by the Marketing Department at Health Imaging. Regional differences may apply to both groups, but the largest difference is between the US market and the rest of the world. Outside the US the product is customized based on local requirements, and the installation and service is done by Kodak. This study did not take into consideration regional or international differences. This was not regarded as a serious limitation since the purpose of the work was to develop and test a model and not to implement an operational PQC system.

6.1.2 Identification of Customer Requirements

Requirements From a Large Hospital

Customer requirements, needs, and expectations were obtained from the Radiology Department at Strong Memorial Hospital, which is the largest hospital in the Rochester area, and Kodak's largest local customer. Requirements were uncovered during a two hour focus group meeting consisting of participants from each of the stakeholders at the hospital. They were:

1. Service technicians that are responsible for maintaining the equipment and keeping it in operation. At Strong Memorial Hospital they also do the installation that is normally done by a dealer.
2. Quality assurance engineers that run capability studies and tests to verify that the processor is operating according to specifications.
3. X-ray technicians that represent the end user of the product, and are responsible for developing the film and pass it on to the radiologist.
4. Administrative personnel whose main task is to procure suitable equipment to fulfill internal needs and requirements.
5. Technical supervisors who make sure that x-ray technicians are able to complete their tasks and notify service technicians if not. They are x-ray technicians with additional administrative duties.
6. Radiologists who utilize the output of the processor, which is developed x-ray film. This group consists merely of medical doctors.

Due to limited resources, some generally accepted guidelines for focus groups like videotaping the session were disregarded. These restrictions may influence the validity of the result. However, the objective was to demonstrate an approach and obtain data suitable for further analysis, and it was felt that this was achieved despite these underlying restrictions.

Requirements From Dealer

The information from the other main customer group, dealers, were obtained through meetings with representatives from S&W X-ray. S&W X-ray is the main local dealer of x-ray products like film, chemicals, processors, general radiology equipment, and x-ray equipment, with 85% of the local market. They are one of the largest dealers in the US with six offices in major upstate New York cities, 140 employees, and total sales of $60 million. About 50% of total sales in Rochester originates from Kodak products, which is higher than their average in other cities. In dollar value, 85% of their processor sales are from Kodak products, where the rest is represented by low end processors used by practitioners. Strong Memorial Hospital is their largest local customer. The data are based on only one dealer, and are therefor not necessarily representative for dealers as an entirety, and the data do not reflect possible regional differences.

Requirements Based on Other Sources

The third source of information was data gathered from production and customer complaint records maintained by Kodak. Customer complaint data are based on customer feedback cards that are completed by the dealer during installation of the product, complaints received by phone, internal testing of the product, meetings with customers, and failure analysis of returned parts. Production data for one year were gathered, grouped, and translated into ten different customer requirements (Appendix A). The same approach was used for customer complaint data (Appendix B). Every requirement based on production data, and most of the requirements based on customer complaints, turned out to be basic requirements (Figure 3.3 The Kano Model, page 29), indicating that relying solely on complaints as customer feedback is inadequate. *Every complaint reflects a situation that will never lead to satisfaction if it is avoided, but result in dissatisfaction as long as it is allowed to occur.* The list of complaints and their translated customer requirements serves as a check list for basic requirements in the QFD matrix (lower left part of Figure 6.4). Translating production and complaint data to customer requirements enables the company to gain basic customer information without conducting a full scale survey. This approach can also be used in other situations, where resources are limited and a basic understanding of customer requirements and needs are required.

6.1.3 Additional Data Obtained From Customers

The importance of each customer requirement and the customer's evaluation of how Kodak meets their expectations regarding each requirement, the performance of the requirement, were determined by a questionnaire. Twenty individuals from different user groups at Strong Memorial Hospital and 7 service technicians and sales representatives from S&W X-ray completed the questionnaire. The response rate where respectively 80% and 88%, which is very high thanks to one person at Strong Memorial Hospital who persistently followed up the survey. The questionnaire was also sent to the Marketing Department at Kodak Health Imaging to see if there were significant differences between the producer's perception of requirements and the customer's. (Only one questionnaire was completed by the Marketing Department because they felt they did not have the necessary knowledge about the use of the product.) The response from Kodak was included in the correspondence analysis (Appendix E) in order to reveal differences between Kodak and their customers, but due to the very limited response rate, no conclusions could be made. The response from Kodak was not included in the consecutive analysis since they are not the customer of the product and should not influence the evaluation of customer requirements.

In addition to some demographic information, the questionnaire consisted of four main parts. The complete questionnaire used at Strong Memorial Hospital, S&W X-ray, and Kodak Health Imaging is presented in Appendix C. The data from the survey can be found in Appendix I.

1. Part I asked about the absolute importance of each customer requirement evaluated on a scale from 1 (*unimportant*) to 9 (*critical*). The survey participants were also asked to identify their most important requirement to give an unambiguous ranking in case of ties between critical requirements.

2. The performance of each requirement compared to expectations were determined on a five point scale ranging from *Much Worse* to *Much Better*. The survey also included questions about the overall performance of the processor to enable a verification of the stated importance of each requirement.

3. The purpose of Part III was to reveal when the customer is satisfied with the performance of their most important requirement and when they become dissatisfied. This part also tried to determine the consequences if the performance of the requirement was unable to meet their expectations. The response rate of this part

was very low, and the data obtained were not directly applicable. This part was reported difficult to understand and too comprehensive. It did however give an indication of the consequences of insufficient performance, and was used as a basis for further cost estimates (Chapter 6.3.4, page 88 and Appendix F, page 119).

4. In part IV the survey participants were asked to rate the performance of the 180LP processor compared to other competing processors from other manufacturers than Kodak. *This part served as a competitive benchmark and was used as customer rating in the QFD matrix* (❻ in Figure 4.1 on page 33). Most of the responses came from the dealer since the hospital only uses Kodak products.

6.1.4 Customer and User Groups (❶ in Figure 4.1 on page 33)

Traditionally, the secondary level of customer requirements in the QFD matrix is based on different customer groups like distributor, retailer, end user, etc. (Chapter 4.1, page 35 and Figure 6.1). The approach is based on the assumption that each customer group is different regarding requirements and their importance, and that the response within each group is uniform. These assumptions were not made in the work described in this text.

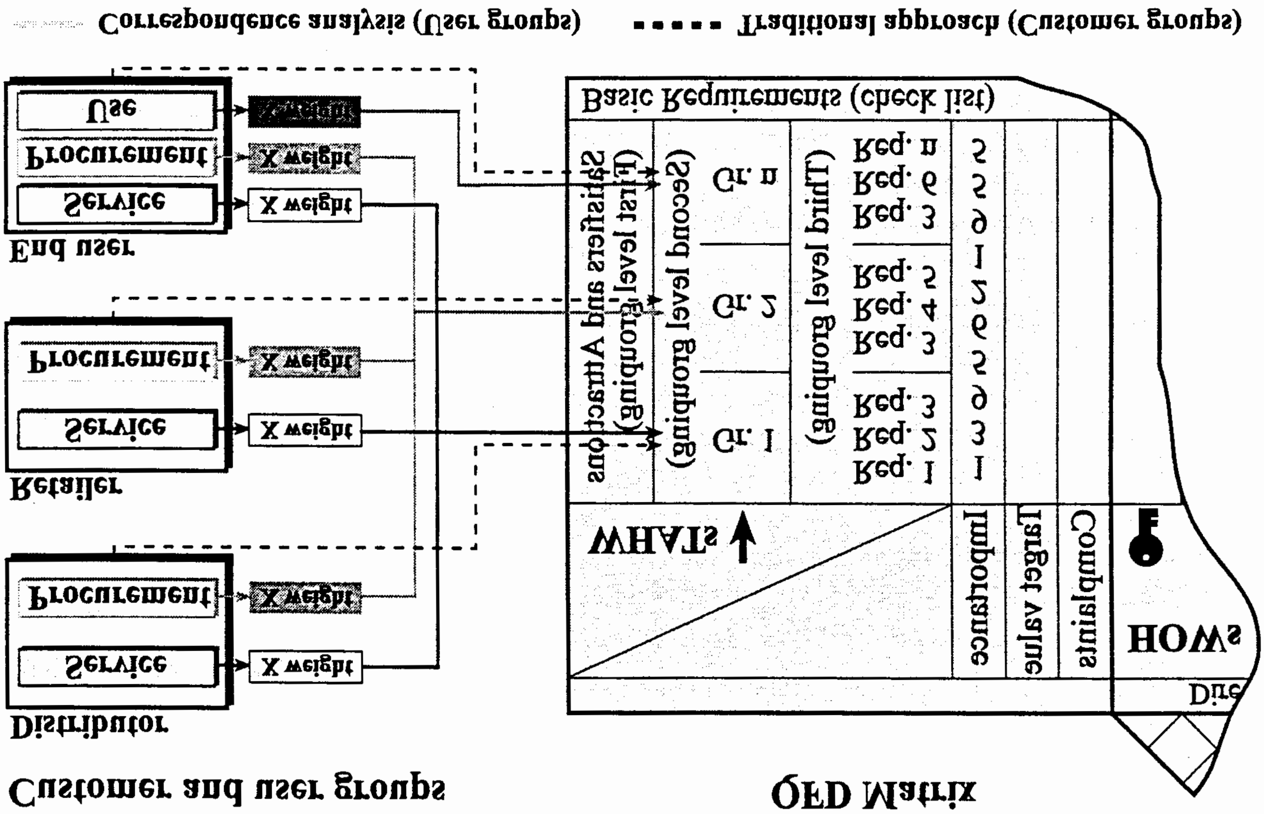


Figure 6.1 Difference Between Customer and User Groups

The ratings of absolute importance were analyzed through correspondence analysis (Nishisato and Nishisato, 1994), to identify different dimensions within the data (a brief overview of correspondence analysis is presented in Appendix D). A dimension is based on groups of people with similar responds to groups of questions, where the purpose is to identify user groups within each customer group. There were several factors justifying this approach:

1. Most likely there do exist differences regarding requirements and their importance within each customer group, and these differences may be more important than differences between different customer groups. Correspondence analysis determines where these differences appear, and which requirements define each dimension.

2. Correspondence analysis determines where differences in requirements are most clearly within each dimension, that is where the respondents disagree most regarding requirements and importance.
3. Correspondence analysis displays who is rating each requirement as important within each dimension, making it possible to form user groups based on uniform perception of importance of specific requirements. These groups may be independent of customer groups.

The purpose of the following analysis is to obtain as accurate as possible picture of which customer or user group that influence each customer requirement, and thereby get a more precise value of importance for each requirement. The value of importance is a main element in the PQC model used to assign priority to improvement activities and estimate intangible costs (Chapter 6.4, page 90).

Due to the limited availability of data, the 1 to 9 rating of importance used in the questionnaire (Appendix C) were translated to a three point scale, to increase the number of entries within each group. 1, 2, and 3 were denoted as 1; 4, 5, and 6 as 2; and 7, 8, and 9 as 3. An observation that was done was that the respondents may have used the scale differently. Some used the entire scale from 1 to 9, while others only used the lower and higher end of the scale or only the middle. It is impossible to determine if this reflects actual perception of importance. The use of a three or five point scale might prevent some of the uncertainty caused by possible differences in the interpretation of the scale. The results of the survey can be found in Appendix I.

The correspondence analysis is based on the use of five dimensions that accounted for 56.3% of the total variation in the data. The considerable error can be explained by the large number of items analyzed (24x3=72) with relatively few respondents (28). The error is not dependent on the number of dimensions. Table 6.1 displays the amount of the total variation each dimension accounts for, which items that explain the dimension, and how important each item is to describe the current dimension. An R-value of 1.0 in Table 6.1 would signify that the item explains the dimension completely. The name in column two is appointed as a common denominator for the items explaining the dimension. The complete result of the analysis can be found in Appendix E, while Appendix D provides a brief overview of correspondence analysis.

It is important to be aware that a dimension determined by correspondence analysis is based on items where the respondents *most strongly disagree*. If the respondents agree on every item within a dimension, either rate them as important or as unimportant, they will not appear as a dimension. The item statistic SS(j) in Appendix E indicates the degree of agreement or disagreement. A low score for SS(j) indicates that the respondents are uniform on the current item within the dimension, while a high sore indicates disagreement between respondents, which is the basis for the dimension.

Table 6.1 User Dimensions Identified Through Correspondence Analysis

Dimension #	Dimension Name	Total variance accounted for	Items with most influence on variance	R-value
1	Serviceability	19.37%	14 Fast and easy to fill chemicals	0.9050
			4 Possible to replace parts without removing other comp.	0.8886
			8 Easy to replace components	0.8656
			10 Possible to upgrade major components and add features	0.7823
			2 Easy access to the interior of the processor	0.7654
2	Use	13.04%	7 Long time between failures and stops	0.7727
			12 Easy connection of plumbing	0.7108
			21 No external pollution from processor	0.6543
			19 Processor able to prevent film mix-up (able to sort film)	0.6306
			18 Processor able to minimize consequences of film jam	0.6158
3	Speed of service and available features	9.69%	22 Processor take care of silver	0.6837
			3 Easy to diagnose and troubleshoot problems	0.6295
			8 Easy to replace components	0.5852
			10 Possible to upgrade major components and add features	0.5778
			2 Easy access to the interior of the processor	0.5773
4	Cost and use	7.57%	16 Low operating costs	0.5903
			5 Spare parts always available when needed	0.5818
			23 Low noise level	0.5763
			15 Low purchasing costs	0.5617
5	Useful life and use	6.64%	9 Processor operates min. 8 years before major overhaul	0.7850
			10 Possible to upgrade major components and add features	0.5492
			13 Hoses out of the way	0.4995
			7 Long time between failures and stops	0.4725
	Total	56.31%		

The column of optimal scores in Appendix E displays how important each respondent rates the items that form the current dimension. The more negative the score is, the more important the respondent has rated the item. These scores were used to group the different job functions in part B of the questionnaire (Appendix C, page 107) into user groups. The data entries from the Marketing department at Kodak were not included in the rest of the analysis since they are not a customer. The weight in the rightmost column in Table 6.2 is a valuation done by Kodak of how each user group influences the purchase and re-purchase decision, and thereby the sales. The following groups were used:

Table 6.2 Groups of Respondents Used in the Analysis

User groups	Job functions	Number of Respondents	Weight
1. Service and Maintenance	Service technicians	8	0.4
	QA technician	1	
	Sales	1	
2. Direct use	X-ray technicians	6	0.1
3. Procurement and Support	Radiologists	3	0.5
	Technical supervision	6	
	Administration	2	
Total (except response from Kodak)		27	1.0

Every consecutive analysis have been based on a 95% confidential interval. Optimal scores (Appendix E) within dimension two to five are normal distributed, but not within dimension 1. However, optimal scores are normal distributed within each group of work place, and within each user group (group of job function) on dimension 1. There is no significant difference in variance between any groups that have been analyzed. Regression analysis revealed that neither how often the respondents were involved with the processor, how many years of experience they had, or how much time they used in connection with the processor had any influence on the respond. The only statistical significant difference could be found between responds and work place, and responds and job function.

Based on the five dimensions from the correspondence analysis and the work place, an analysis of variance showed that there was a significant difference between Strong Memorial Hospital and S&W X-ray regarding dimension 1 (Table 6.3). No such difference could be found between the work place and any other dimension.

Table 6.3 Variation in Dimension 1 based on Work Place

Analysis of Variance on Serviceability (Dimension 1) based on Work Place:

Source	DF	SS	MS	F	p
Work Place	1	1.658	1.658	5.11	0.033
Error	25	8.105	0.324		
Total	26	9.762			

```
                                   Individual 95% CI's For Mean Based on Pooled StDev
Level        N      Mean     StDev   --------+---------+---------+---------+---
Strong      20    0.1640    0.6454                        (--------*--------)
S&W          7   -0.4014    0.1779   (-------------*-------------)
                                     --------+---------+---------+---------+---
Pooled StDev =    0.5694                 -0.70     -0.35      0.00      0.35
```

There was also significant difference between user groups (groups of job functions) on dimension 1 (Table 6.4). However, considering the underlying data, it was assumed that the difference between work place is based on obliqueness in the responses. The data from Strong consisted of responses from all three user groups, with only three entries in group 1, while the data from S&W were only from group 1. If the analysis of variance based on user groups is considered on dimension 1 (Table 6.4), it can be seen that user group 1 is significantly different from user group 2 and 3.

These observations support the assumption that work place has no influence on responses, and is not suitable for grouping in the QFD matrix. The variation that can be seen in Table 6.3 is due to the skewness of the number of objects within each user group at Strong Memorial Hospital. Different user groups on the other hand have great influence on responses for dimension 1, indicating that these groups may be more suitable to use as groups in the QFD matrix, with different importance attached to them.

Table 6.4 Variation in Dimension 1 based on User Groups (Groups of Job Functions)

Analysis of Variance on Serviceability (dimension 1) based on Job Function:

Source	DF	SS	MS	F	p
Job Function	2	2.970	1.485	5.25	0.013
Error	24	6.792	0.283		
Total	26	9.762			

```
                                   Individual 95% CI's For Mean Based on Pooled StDev
Level      N     Mean    StDev   ----------+--------------+--------------+--------------+
Group 1   10  -0.4140   0.1713   (----------*----------)
Group 2    6   0.3100   0.6249                  (-------------*-------------)
Group 3   11   0.2500   0.6764                     (----------*----------)
                                 ----------+--------------+--------------+--------------+
Pooled StDev =  0.5320                   -0.50           0.00           0.50           1.00
```

Further analysis revealed that there were no statistically significant differences between user groups (groups of job functions) on dimension 2 (Table 6.5). However, the analysis of variance does indicate a difference between user group number 1 and user group number 2 and 3. The lack of statistical significance on a 95% confidence interval may be caused by the considerable variation within each group, which again is due to the limited number of respondents. It is believed that if the number of respondents had been much larger than the number of items, there would have been a statistically significant difference between user group 1 and user group 2 and 3 on dimension 2.

Table 6.5 Variation in Dimension 2 based on User Groups (Groups of Job Functions)

Analysis of Variance on Dimension 2 based on Job Function

Source	DF	SS	MS	F	p
Job Function	2	0.566	0.283	1.17	0.328
Error	24	5.824	0.243		
Total	26	6.390			

```
                                   Individual 95% CI's For Mean Based on Pooled StDev
Level      N     Mean    StDev   -------------+--------------+--------------+-------------
Group 1   10   0.2080   0.6343                      (----------------*----------------)
Group 2    6  -0.1083   0.3416   (--------------------*--------------------)
Group 3   11  -0.0818   0.4024             (--------------*--------------)
                                 -------------+--------------+--------------+-------------
Pooled StDev =  0.4926                      -0.30          -0.00           0.30
```

Dimension 3 (Table 6.6) did show a strong difference between user group 1 and 2, and user group 3, and dimension 4 (Table 6.7) showed a strong difference between user group 1 and 3, and user group 2. This indicates that within these dimensions the different user groups have different priorities, that have to be considered when the overall importance for each requirement is determined.

Table 6.6 Variation in Dimension 3 based on User Groups (Groups of Job Functions)

Analysis of Variance on Dimension 3 based on Job Function

Source	DF	SS	MS	F	p
Job Function	2	1.271	0.636	4.24	0.027
Error	24	3.602	0.150		
Total	26	4.874			

```
                                     Individual 95% CI's For Mean Based on Pooled StDev
Level      N     Mean      StDev     -----------+--------------+--------------+--------------+
Group 1   10   -0.1780    0.3617         (------------*------------)
Group 2    6   -0.1500    0.4316     (-----------------*-----------------)
Group 3   11    0.2736    0.3864                            (-------------*-------------)
                                     -----------+--------------+--------------+--------------+
Pooled StDev =  0.3874                        -0.30          -0.00           0.30           0.60
```

Table 6.7 Variation in Dimension 4 based on User Groups (Groups of Job Functions)

Analysis of Variance on Dimension 4 based on Job Function

Source	DF	SS	MS	F	p
Job Function	2	0.967	0.484	3.91	0.034
Error	24	2.969	0.124		
Total	26	3.936			

```
                                     Individual 95% CI's For Mean Based on Pooled StDev
Level      N     Mean      StDev     --+--------------+--------------+--------------+---------
Group 1   10   -0.0990    0.2669     (-----------*------------)
Group 2    6    0.3567    0.4031                        (--------------*--------------)
Group 3   11   -0.0982    0.3892     (-----------*------------)
                                     --+--------------+--------------+--------------+---------
Pooled StDev =  0.3517              -0.30          -0.00           0.30           0.60
```

Dimension 5 (Table 6.8) did not reveal a significant difference between the user groups, but the analysis of variance resulted in the same situation as for dimension 2. There seems to be two groups, user group 1 and 2, and user group 3, but the variance within each user group is too large to make the difference significant. The same assumption was made as for dimension 2, that with more respondents there would be a significant difference between user groups on dimension 5.

Table 6.8 Variation in Dimension 5 based on User Groups (Groups of Job Functions)

Analysis of Variance on Dimension 5 based on Job Function

Source	DF	SS	MS	F	p
Job Function	2	0.402	0.201	1.60	0.223
Error	24	3.014	0.126		
Total	26	3.416			

```
                                     Individual 95% CI's For Mean Based on Pooled StDev
Level      N     Mean      StDev     --------------+--------------+--------------+--------------
Group 1   10   -0.1250    0.4416       (-----------------*-----------------)
Group 2    6   -0.0717    0.2655     (-----------------------*-----------------------)
Group 3   11    0.1400    0.3011                     (-----------------*-----------------)
                                     --------------+--------------+--------------+--------------
Pooled StDev =  0.3544                           -0.20          -0.00           0.20
```

The analysis of variance of each dimension regarding the three user groups indicates that the chosen groups explain differences between dimension fairly well. It is thus assumed appropriate to use these three user groups in the secondary level of customer requirements, as illustrated in the QFD matrix in Figure 6.1 on page 66, instead of the two main customer groups.

Another application of correspondence analysis is to determine which overall questions that should be asked to interpret the overall performance of the product. The survey that was accomplished in this study would have been regarded as a pilot study in a full scale analysis. Questions about overall performance in the final survey should be based on a correspondence analysis of individual ratings of how each customer requirement is met, revealed through the pilot survey. Appropriate overall questions can then be formed based on differences within each user group to best indicate where performance needs improvement. For instance, the overall question "How is the reliability of the processor?" in the questionnaire in Appendix C is aimed at dimension 1 (Serviceability in Table 6.1). The second overall question "How is the user friendliness?" is most suitable for dimension 2 (Use in Table 6.1).

A Forced Classification correspondence analysis, where one overall question is included in the final performance data at the same time with a high weight, to make sure they dictate the dimension, will reveal if the responses from the final survey are in line with the pilot survey. This analysis will uncover regional and other differences between the respondents. A full scale survey is beyond the scope of this project, and further analysis has not been included.

6.1.5 Overall Importance of Customer Requirement (❸ in Figure 4.1 on page 33)

There were large differences within groups of respondents for some requirements. This may be due to different personal perceptions, but it may also be because the same questionnaire was used for all respondents, and every question was not applicable to everyone. To overcome this problem, the questionnaire was evaluated based on knowledge about each groups ability to evaluate each requirement and rating of performance. Only relevant requirements were included for each user group (gray columns in Table 6.9 have *not* been included in the analysis). Empty entries indicate questions that have not been completed by the respondent. Every requirement was rated from 1 (*unimportant*) to 9 (*critical*). A more comprehensive description of the survey results can be found in Appendix I. The first column in Table 6.9 indicates which group the respondents belong to, identified through correspondence analysis (as described in Table 6.2), and the weight the group was given by Kodak. The second column which job function they have, and the third column where they work (WP = Work Place). 1 is Strong Memorial Hospital, 2 is S&W X-ray, and 3 is Kodak. The description of each requirement corresponding to the numbers on the top of the table can be found in the questionnaire (Appendix C).

Table 6.9 Absolute Importance of each Customer Requirement for each User Group

	Job Function	P (W)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	Service tech	1	8	8	7	8	9	7	6	8	7	7	5	6	6	6	3	3	7	6	3	6	5	3	3	5
	Service tech	1	4	8	8	8	8	8	8	7	6	6	5	7	7	6	5	7	7	8	5	8	6	3	8	8
	Service tech	2	9	9	8	7	9	9	9	6	5	1	1	1	9	5	5	5	9	9	1	9	9	1	5	5
User	Service tech	2	2	9	7	7	8	8	7	8	1	8	3	8	8	6	4	4	8	8	5	9	9	8	8	6
Gr. 1	Service tech	2	2	9	9	9	9	9	7	9	4	8	9	9	9	9	1	1	9	8	9	9	7	8	5	6
	Service tech	2	8	8	8	8	8	8	8	8	8	8	8	8	8	8	9	9	9	9	9	9	9	9	8	7
W =	Service tech	2	8	6	6	7	9	6	6	7	7	8	6	6	6	6	6	6	9	9	6	6	6	6	6	6
0.4	Service tech	2	9	8	9	7	9	7	9	7	9	8	9	9	8	8	8	8	9	9	8	8	8	6	7	8
	Sales	2	9	7	7	7	9	7	6	6	6	6	5	5	5	6	7	4	5	5	6	9	8	5	5	6
	QA tech	1	7	7	7	7	7	7	7	7	5	5	5	7	7	7	5	6	8		5	7	7	7	5	7
	Average imp.		6.6	7.9	7.6	7.5	8.5	7.6	7.3	7.3	5.8	6.5	5.6	6.6	7.3	6.7	5.3	5.3	8.0	7.9	5.7	8.0	7.4	5.6	6.0	6.4
	X-ray tech	1	7	1	1	1	7	9	9	1		1	9		7	1	1	1	9	7	1	7	7	1	7	7
User	X-ray tech	1	9	7	7	5	7	7	9	7	4	4	7	2	6	5	4	4	9	9	5	7	7	7	7	7
Gr. 2	X-ray tech	1	5	9	6	5	9	9	9	9	7	7		9	8	8	9	9	7	9	9	9	9	8	8	9
	X-ray tech	1	6	7	6	6	6	8	8	6	3	4	2	2	2	3	2	2	8	8	7	9	7	2	8	9
W =	X-ray tech	1	1	1	8	1	1	5	5	1	1	1	8	1	8	1	1	1	9	9	8	5	5	1	5	8
0.1	X-ray tech	1	7	1	9	1	5	9	9	3	7	1	8	1	5	1	1	1	9	9	8	9	5	1	1	9
	Average imp.		5.8	4.3	6.2	3.2	5.8	7.8	8.2	4.5	4.4	3.0	6.8	3.0	6.0	3.2	3.0	3.0	8.5	8.5	6.3	7.7	6.7	3.3	6.0	8.2
	Radiologist	1	6	6	6	5	7	9	9	6	7	5	4	3	2	5	8	7	9	7	4	8	7	6	7	7
	Radiologist	1	6	3	9	3	7	9	9	3	7	7	3	3	3	3	5	7	9	9	9	7	7	7	5	7
	Radiologist	1	9	9	9	1	1	9	9	1	1	1	1	1	1	1	9	9	9	9	9	4	9	5	5	9
User	Admin.	1	9	1	1	1	1	9	1	9	9	9	1	1	1	9	9	9	9	9	9	9	9	9	9	9
Gr. 3	Admin.	1	6	6	9	9	8	9	7	9	8	7	6	7	6	7	5	5	6	5	5	8	6	8	8	6
	Tech superv.	1	1	3	4	1	1	4	6	1	1	1	1	1	1	1	4	4	9	9	9	3	5	5	6	9
W =	Tech superv.	1	9	5	5	5	9	9	9	5	5	5	8	5	5	5	7	7	9	7	5	8	5	5	8	8
0.5	Tech superv.	1	1	3	7	3	3	8	8	5	3	5	2	3	7	1	5	5	9	7	8	7	9	5	8	9
	Tech superv.	1	8	7	6	7	8	7		8	7	8			5	7	6	6	9	8	8	9	9	8	7	8
	Tech superv.	1	7	5	4	2	4	7	2	3	3	3	1	1	2	2	5	5	8	8	9	7	8	6	7	8
	Tech superv.	1	5	3	7	3	7	6	6	3	1	1	1	1	1	1	1	1	8	7	6	2	1	1	1	9
	Average imp.		6.1	4.6	6.1	3.6	5.1	7.8	6.6	4.8	4.7	4.7	2.8	2.6	3.1	3.8	5.8	5.9	8.5	7.7	7.4	6.5	6.8	5.9	6.5	8.1
	Marketing	3	9	7	9	7	9	8	8	8	7	7	8	7	7	7	8	8	8	8	7	9	9	8	7	8
	Overall imp.		5.7	3.2	3.7	3.0	3.4	7.7	7.0	2.9	4.7	5.3	0.7	2.6	0.6	2.7	2.9	3.0	8.3	7.9	4.3	7.2	4.1	2.2	3.8	4.9

The estimated weight each group was given regarding the purchase and re-purchase decision (Table 6.2 on page 68) has been used to accommodate between-group differences. A weighted importance for each applicable requirement in each group was calculated based on the average importance in the group. The overall importance for each requirement was calculated as the sum of weighted importance from each group, as in Table 6.10. The complete overview of importance for every customer requirement can be found in Figure 6.4 on page 76.

Table 6.10 Weighted and Overall Importance for Customer Requirements

Group	Req.	AI = Average Importance (Table 6.9)	W = Weight (Table 6.2)	Weighted Importance = AI x W
	1	6.6	0.4	2.64
1.	2	7.9	0.4	3.16
Service and	3	7.6	0.4	3.04
maintenance	6	7.6	0.4	3.04
	...	...	...	...
2.	3	6.2	0.1	0.62
Direct use	6	7.8	0.1	0.78
	...	...	...	...
3.	1	6.1	0.5	3.05
Procurement	6	7.8	0.5	3.90
and indirect	7	6.6	0.5	3.30
involvement	9	4.7	0.5	2.35
	...	...	...	...

⇒

Req.	From Group	Overall Importance
1	1+3	5.7
2	1	3.2
3	1+2	3.7
6	1+2+3	7.7
7	3	7.0
9	3	4.7
...	...	...

6.1.6 Competitive Satisfaction Performance to Measure Intangible Poor Quality Costs (❻ in Figure 4.1 on page 33)

The customers' rating of competing products, compared to the 180LP processor, were completed by 7 respondents (Table 6.11). Fuji is Kodak's chief competitor in the processor market, and only Fuji models were chosen for the evaluation of competitive satisfaction performance. The three different models from Fuji were evaluated as fairly similar, and treated as one to increase the number of responds.

Table 6.11 Sources of Competitive Data

Job Function	Work Place	Competing Product
Service Technician	Strong Memorial Hospital	Fuji FYIX
Service Technician	S&W X-ray	Fuji 422
Service Technician	S&W X-ray	Fuji FL-IM 3543
Service Technician	S&W X-ray	Fuji 422
Service Technician	S&W X-ray	Fuji 422
Clinical Technician	Strong Memorial Hospital	X-omat 480RA (Kodak)
Marketing	Kodak Health Imaging	3M 969 Laser Processor

Respondent	Requirements 1	2	3	4	5
1	2	3	3	2	1
2	2	1	1	1	1
3	2	1	1	1	1
4	3	2	2	1	2
5	3	1	2	1	1
Average	2.4	1.6	1.8	1.2	1.2

÷

Respondent	Requirements 1	2	3	4	5
1	3	3	3	4	4
2	4	3	5	4	5
3	3	2	3	3	4
4	0	5	5	4	3
5	3	5	4	4	5
Average	3.3	3.6	4.0	3.8	4.2

=

	Requirements 1	2	3	4	5
Avg. A - Avg. B	-0.9	-2.0	-2.2	-2.6	-3.0

Figure 6.2 Performance Index

The average performance of each requirement for the 180LP processor, based on the five respondents (Appendix C, Section II), were subtracted from the average of their competitive evaluation (Appendix C, Section IV), to obtain a performance index (P_i) for how each customer requirement was met (see Chapter 4.7). A negative performance index indicates that the 180LP performs better than its competitor. A complete overview of how each customer requirement was met can be found in Figure 6.4 on page 76. The performance index is used to estimate intangible costs. The number of respondents is too low to make any conclusions regarding the performance of the 180LP processor compared to the competitor, and the response is most likely influenced by the strong position Kodak has in Rochester. However, the approach used to obtain the result is applicable.

6.1.7 Selection of Customer Requirements for Further Analysis

Considering the average importance of each requirement, and the average rating of performance within each user group, a priority was calculated and used to choose requirements for further analysis and translation to technical responses (data can be found in Appendix I). The thought is that there is no point improving a requirement that is important, if the current performance is better than the chief competitor. On the other hand, if the performance is much worse than the chief competitor, it might be necessary to improve even if the importance is relatively low. The priorities were calculated as:

$$\text{Priority} = \sum_{n=1}^{3} \frac{\text{Average Importance}_{\text{Group } n} \times \text{Weight}_{\text{Group } n}}{\text{Average Performance}_{\text{Group } n}}$$

This result in the following priority index for customer requirement number 17:

$$\text{Priority}_{17} = \frac{8.0 \times 0.4}{3.0} + \frac{8.5 \times 0.1}{3.2} + \frac{8.5 \times 0.5}{3.6} = 2.51$$

The average importance and weight of each user group for requirement 17 can be found in Table 6.9. Average performance is reproduced in the second table in Appendix I. The first part of the equation represents average data for user group 1 (Service and maintenance), the second part for user group 2 (Direct use), and the third for user group 3 (Procurement and indirect involvement).

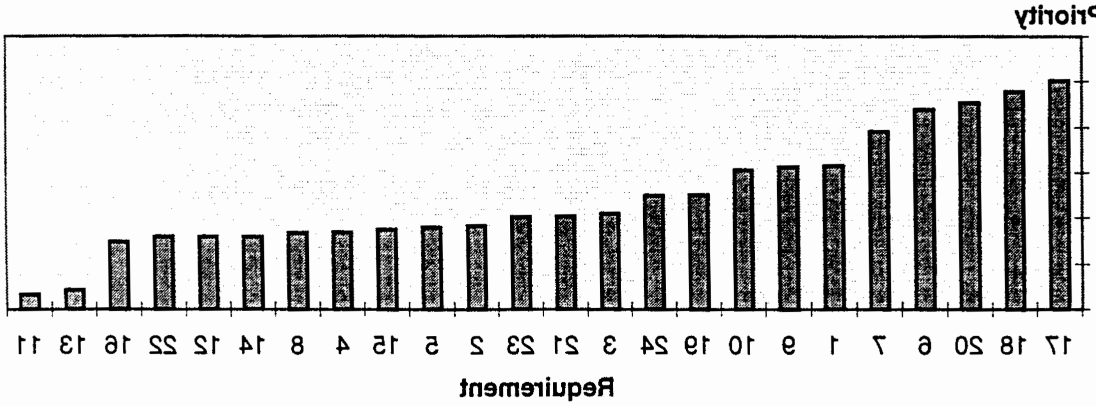


Figure 6.3 Priority for Further Analysis

6.1.8 Target Values Expressed by Customers (❹ in Figure 4.1 on page 33)

Target values for each customer requirement were identified both through the survey and later verified by representatives from Strong Memorial Hospital and S&W X-ray. The inputs from the survey (Appendix C, part III) were not directly applicable, but an overall evaluation of responds for each requirement gave an indication on what the customer expected from the processor. Target values in the QFD matrix (Figure 6.4 on page 76 and Figure 6.5 on page 79) are based on when the customer is satisfied, that is, when further improvement in the performance of the requirement will not lead to additional customer satisfaction. The target value for the customer requirement that was further analyzed was determined as a scale, where the lower limit is based on when the customer is completely satisfied with how the requirement is met, and the upper limit when they become dissatisfied. Shifts in performance were identified between these outer limits, and used to construct different sections of the loss function monitoring external and customer incurred PQCs (Chapter 6.3.3 and 6.3.4).

6.1.9 Summary of Customer Requirement Data

Figure 6.4 is an extract of the completed QFD matrix that can be found on page 79. Two requirements, *processor able to prevent film mix-up (able to sort film)* and *processor takes care of silver (silver recovery)*, were identified as features because it was impossible to determine their target values. Features are provided or not provided, and are not actual customer requirements that should be included in the cost analysis. However, they may be included in the QFD matrix to visualize that the customer requires these features and how important they consider them. One of the features, processor able to prevent *film mix-up*, is provided in a model called 180 LPS (S for sorter). The fact that this requirement was identified by the customer, but not provided on their models, may be due to administrative cost/benefit evaluation or an insufficient sales job done by the dealer or Kodak. If a feature receives high importance, but is not provided on any model (*processor takes care of silver*), the benefit of providing this features should be evaluated by the manufacturer. If nobody provides a specific feature they should be considered attractions, that may lead to competitive advantages if provided.

HOWs are not included to save space

Service and Maint. / Direct Use, Procurement and Support / Salesmen and Attractions

WHATs	Importance	Target Value	Imp direction	Complaints	Performance	Cost Index
1 Fast and timely first time delivery of pros. and comp.	5.7	day	O		-0.9	0.00
2 Easy access to interior of processor	3.2	1mi	↓		-2.0	0.00
3 Easy to diagnose and troubleshoot problems	3.7	20mi	↓		-2.2	0.00
4 Possible to replace parts without moving other comp.	3.0	10mi	↓		-2.6	0.00
5 Spare parts always available when needed	3.4	1h	↓		-3.0	0.00
6 Fast recovery after problems and stops	7.7	30mi	↓		-1.4	0.00
7 Long time between failures and stops	7.0	2mo	↑	38	-0.4	0.00
8 Easy to replace components	2.9	1h	↓		-2.2	0.00
9 Pros. operates min. 8 years before major overhaul	4.7	8y	↑		-0.3	0.00
10 Possible to upgrade major comp. and add features	5.3		↑		-1.2	0.00
11 The processor have a small footprint	0.7	12ft²	↓		-0.4	0.00
12 Easy connection of plumbing	2.6	1.5h	↓		-0.6	0.00
13 Hoses out of the way	0.6		↓		-0.6	0.00
14 Fast and easy to fill chemicals	2.7	5mi	↓		-1.0	0.00
15 Low purchasing costs	2.9	$20K	↓		0.0	0.00
16 Low operating costs (monthly)	3.0	$500	↓		0.0	0.00
17 No film jams in processor	8.3	1mo	↓		-0.2	0.00
18 Pros. able to minimize consequences of film jam	7.9		↑		-1.0	0.00
19 Processor able to prevent film mix-up (feature)	4.3	—	O		-1.3	0.00
20 No leaks of chemicals	7.2	2y	↓	6	-0.2	0.00
21 No external pollution from processor	4.1	0	↓		-0.2	0.00
22 Processor take care of silver (feature)	2.2	—	O		0.0	0.00
23 Low noise level	3.8	dB	↓	4	0.2	0.76
24 High processing speed	4.9	60s	↑		-1.0	0.00
Basic Requirements (see Appendix A and Appendix B)	ΣI=101.8					ΣCI=0.76

Customer Rating (0 1 2 3 4 5): --- Fuji, — Kodak

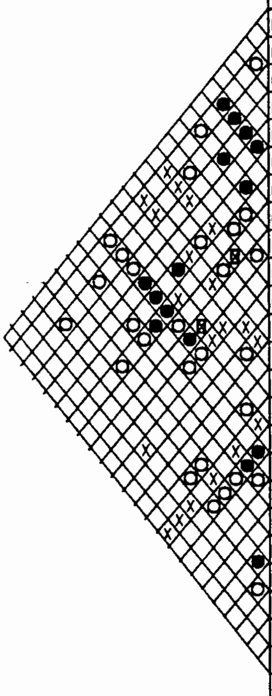


Figure 6.4 *Customer Requirement Data from Strong Memorial Hospital and S&W X-ray*

6.2 ANALYSIS AT KODAK EQUIPMENT & SCREEN SYSTEMS

The assembly area is process oriented where all 19 products are produced on the same line through 23 different main processes. Each process is broken down into 1 to 19 consecutive operations based on the amount of work needed in each process. Each process is either sequenced to customer order, build to KANBAN signal, or parallel operations. There are feeder lines that "feed" directly into each process. Quality control is performed each time a product enters a new work station (process) and failures from the previous work station are normally revealed before the product reaches final testing.

6.2.1 Key Process Parameters (Technical Responses, ❺ in Figure 4.1 on page 33)

Considering the evaluation that was done in Chapter 6.1.7, key process parameters were identified for customer requirement number 17, no film jams in processor, and requirement number 20, no leaks of chemicals. Requirement number 18, which had the second highest priority, was considered too similar to requirement number 17 and not used for further analyses. Key process parameters were identified during a two hour meeting in a cross functional team at Kodak Health Imaging. The team consisted of eight representatives from Production, Product Development, Quality Assurance, and Marketing. The sub-system of the processor that influence the fulfillment of the customer requirement was first identified, and used as the top level in the QFD matrix (Figure 6.5, page 79). Each key process parameter is then displayed under each heading (sub-system). The analysis resulted in more than the recommended 1-3 key process parameters for each customer requirement, but every key process parameter was included in the matrix to provide a complete picture. This could be done since only two requirements were analyzed, but when the PQC model is used in full scale, the number of responses should be limited to prevent over-complexity. The delimitation should be based on importance of each key process parameter regarding its effect on the fulfillment of the customer requirement (strongly linked ●) and by grouping similar key process parameters. Identified key process parameters are displayed in Figure 6.5, on page 79.

6.2.2 Relationship Between Elements in the Matrix and Types of Characteristics

Relationships between each element in the QFD matrix (the "body" and the "roof" of the matrix) are not of critical importance to the PQC model, but they represent valuable information for the quality improvement team that is going to reduce PQCs. The "roof" outside the customer portion of the matrix have been added to give an easy overview of how changes in the fulfillment of one customer requirement will affect other requirements. This correlation matrix is normally not a part of the QFD matrix. Considering the relationship table (body) of the QFD matrix, three key process parameters for customer requirement number 17 were chosen for further cost analysis. These were the key process parameters that were strongly linked to the customer requirement. Identified key process parameters for customer requirement number 20 were not used in the consecutive cost analysis since it was felt that this would only be a repetition of the analysis done for requirement number 17, and would not provide any new information for the verification of the PQC model. The use of the QFD matrix for cost analysis is not covered in traditional QFD approaches, but represent an extended utilization of an already powerful tool.

Key process parameters were only identified for two customer requirements, but the relationship table shows that there are also possible or moderate linkages to other requirements. However, strong linkage should only exist to the requirements that were chosen, otherwise identical customer requirements have been placed in the matrix and they should probably be combined. Most of the key process parameters that were identified were of the type target-the-best, as opposed to customer requirements that were mainly of the type smaller-the-better or larger-the-better. This is because the customer often indicates how much of a specific characteristic he or she wants, while the key process parameter mainly will be measured as tolerances necessary to oblige to the customer's requirements.

6.2.3 Operational Goals and Targets (❹ in Figure 4.1 on page 33)

The selected key process parameters were not presently measured at Kodak, and operational goals did not exist. The cross functional team had to estimate these goals based on experience. Estimated operational goals were used as limits in the loss function used to measure internal failure costs (Chapter 6.3.2). Every operational goal was of the type target-the-best with two-sided tolerance limits. The target value was set to zero and tolerances were measured as relative deviations from this target value. Operational goals and targets can be found in Appendix F.

6.2.4 Performance of Key Process Parameters (❺ in Figure 4.1 on page 33)

Estimating the performance of each key process parameter would be nothing but guesswork. A comprehensive benchmark study would have been necessary to obtain reliable data, something that is beyond the scope of this project. The representatives from Kodak did not feel competent to make any estimates, and reliable data were not available, so this part of the QFD matrix has not been completed. This part is the key to measuring lack of process efficiency costs, which have been left as suggestions for further research.

6.2.5 Summary of the QFD Matrix

Figure 6.5 provides a summary of the information that was gathered at Kodak Health Imaging, Strong Memorial Hospital, and S&W X-ray. The information has been used in consecutive chapter to calculate various elements in the PQC model.

The importance to the right of each customer requirement is the overall weighted importance that was determined in Chapter 6.1.5. The weighted importance is used in Chapter 6.4 to calculate intangible PQCs and for directly prioritizing quality improvement activities. The target value in the next row of the QFD matrix is the values the customer (Strong Memorial Hospital) said they expected to stay satisfied with the performance of the product (including service and other support activities). Number of complaints are based on one year of complaint records described in Appendix B.

The body of the matrix describes the relationship between each customer requirement and each key process parameter. The heading above the key process parameters represents sub-systems of the processor. The roof shows the correlation between each key process parameter, and the "roof" on the right side the correlation between each customer requirement. Operational goals and targets are tolerances that is estimated by the cross functional team at Kodak. Performance within these tolerances are assumed to result in customer satisfaction. Operational goals and targets have been used in Chapter 6.3.2 to calculate internal failure costs.

The customer rating, performance index (P_i), and cost index (CI_i) describes the performance of the 180LP processor compared to the chief competitor's processor (Fuji). This rating is used in Chapter 6.4.2 to link potential intangible PQCs to actual process performance.

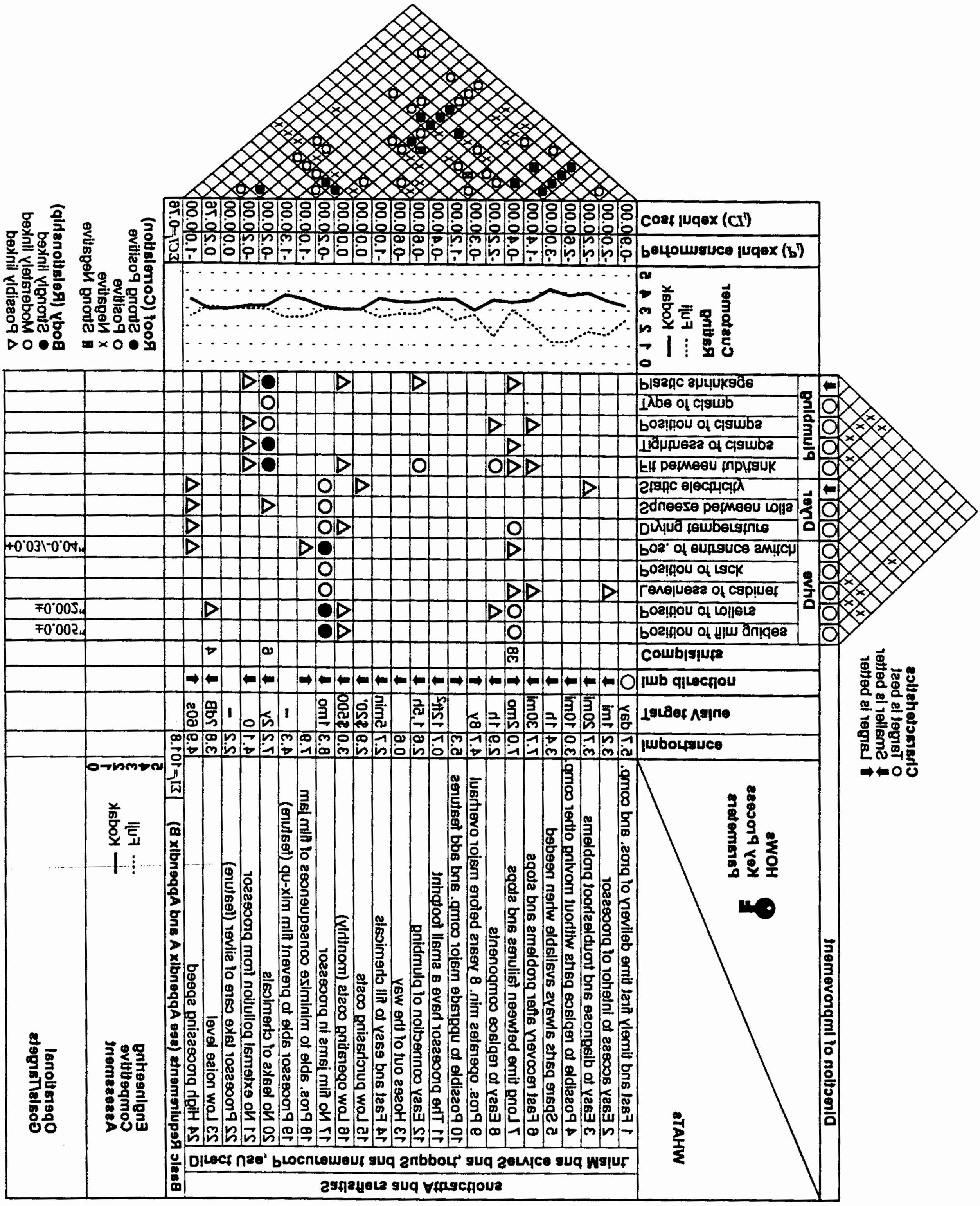


Figure 6.5 Complete QFD Matrix from the Case Study at Kodak

6.3 CONSTRUCTION OF LOSS FUNCTIONS

Only key process parameters that were strongly linked to customer requirement number 17 were chosen for further analysis and construction of loss functions. The objective was not to obtain an overall cost picture for the current product, but demonstrate how loss functions could be constructed based on customer requirements. Internal failure costs are based on key process parameters that have been summed up to customer requirements, while external failure costs and customer incurred costs are directly based on each customer requirement. Environmental costs has not been considered. *The customer will normally not experience key process parameters directly, only the effect they have on the performance of their requirements.* Sales prices have been used as cost basis for major components (processors and printers), both internally and externally, since revenue is considered strictly confidential information. Costs of components have been left out due to restrictions from Kodak. However, these limitations do not influence the approach or the result of the analysis.

6.3.1 Gathering Cost Data

Process data required as input to the loss function were gathered separately for each cost category (Chapter 5.4, page 58). Internal and external costs were determined based on information from Kodak Health Imaging, while customer incurred costs were gathered at Strong Memorial Hospital. Environmental costs were not analyzed as previously explained in Chapter 3.2.3. Data were gathered using the same form for each cost category (Figure 6.6), where the key process parameter entries were only applicable for internal failure costs. Completed forms can be found in Appendix F.

Customer requirement: No film jams in processor

Cost category: ☒ Internal Failure ☐ Exernal Failure ☐ Customer Incurred ☐ Environmental

Key process parameters: Position of film guides

Type of characteristic: ☐ Smaller-the-better ☒ Target-the-best ☐ Larger-the-better

Performance; Satisfied: < ± 0.005"

Shift: < ± 0.010"

Dissatisfied: > ± 0.010"

Failure/non-conformance: Assembly holes in wrong position
Wrong curvature of guide shoe
Wrong position of stiffener

Cost driver: Number of failures per processor

CONSEQUENCES:

ACTIVITIES	COST ELEMENTS																
	Labor				Material				Process				Facility				Total for
	Direct		Indirect		Direct		Indirect		Direct		Indirect		Direct		Indirect		Cost Dr.
	Who	Time	Who	Time	What	Vol.	What	Vol.	Which	Time	Which	Time	Which	Area	Which	Area	
Notify service																	
Troubleshooting																	
Repair/recovering																	
Rerouting of print																	
Reprinting																	
Etc.																	

Labor Cost: **Material Cost:** **Process Cost:** **Facility Cost:**

Figure 6.6 Form Used to Determine Cost Data for the Loss Function

Performance is based on how the customer requirement or key process parameter meets expectations. Satisfied indicate that a further improvement in performance will not result in additional benefits. A shift in performance indicates that additional activities have to be performed to oblige to specified requirements. This might be rework done by the manufacturer or additional service operations done by the customer. Dissatisfaction shows when the performance of the characteristic influencing the customer requirement or key process parameter becomes totally unacceptable. This will lead to scrap at the manufacturer or discontinued use of the product at the customer. Failures and non-conformance are elements that influence the performance of the key process parameter or the fulfillment of the customer requirement. Consequences are activities that have to be undertaken when a failure or non-conformance occurs. They are measured by:

- Labor costs, where direct represent the individuals that accomplish the activity, and indirect represent time spent by those that are affected by the activity (waiting). The total labor cost is determined by who is involved, for how long, and their salary.
- Material costs represent materials that are lost due to the failure. Total costs are driven by type, volume, and unit cost.
- Process costs represent costs of running a process. If rework has to be done, or the process is down because of a failure, process costs occur due to lost capacity.
- Facility Costs represent the cost of the space of the process. If a process is down, there will be no output to pay for the facility, and these costs have to be included in the failure cost element.

Costs are driven by activities that consume resources, where the overall cost driver has been used as input to the loss function (lower right cell of the consequence table in Figure 6.6). This approach represents a simplified Activity Based Cost system (Chapter 3.1.2 on page 26).

6.3.2 Internal Failure Costs

Internal failure costs have been estimated for key process parameters that is believed to have the strongest influence on the fulfillment of the customer requirement. Tolerances and shifts in performance are based on qualified guesses made by representatives from Kodak Health Imaging. The performance of each characteristic is not presently measured, and a centered normal distribution with a standard deviation of 1/8 of the total tolerance interval has been assumed. Each key process parameter has been analyzed separately on individual forms (Appendix F), and later summarized to obtain an overall internal failure cost for the customer requirement. Each loss function represents a target-the-best characteristic with one shift and a target value T=0. The calculation of the loss for a target-the-best characteristic has been derived in Chapter 5.3.1. Every consecutive calculation is similar, only with different tolerance limits, shifts in performance, standard deviations, and costs. The estimated loss, based on the loss function and the performance of the key process parameter, has been calculated by the Microsoft Excel function described in Appendix G.

Customer requirement: No film jams in processor (Appendix F, page 120)
➊ Position of film guides
Film guides direct the film when it enters the processor and when it transfers between different racks in the processor. This is mainly a curved piece of sheet metal with two assembly holes and a stiffener on the back. Common failures that bring the film guide out of position is wrong position of assembly holes, wrong curvature of guide shoes, and wrong positioning of the stiffener. A failure can either be detected at the work station where the film guide is mounted, or later at setup and testing. If the failure is detected at setup and testing the consequences are more severe, and a shift in the loss function occurs. The film guide is normally replaced for every failure, not repaired.

The following characteristics are used in the loss function (see Chapter 5.2.2, page 51 for formulas and explanation):

Table 6.12 Loss Data for Internal Failure Costs, No Film Jams in Processor - Position of Film Guide

L_1 = -0.01	c_1=\$105.30	$k_1=\frac{105.30-15.80}{(0+0.01)^2-(0+0.005)^2}=1,193,333$	$a_1=\frac{(105.30-15.80)(0+0.005)^2}{15.80((0+0.01)^2-(0+0.005)^2)}=0.53$
L_2=-0.005	c_2= \$15.80	$k_2=\frac{105.30-15.80}{(0.01-0)^2-(0.005-0)^2}=1,193,333$	$a_2=\frac{(105.30-15.80)(0.005-0)^2}{15.80((0.01-0)^2-(0.005-0)^2)}=0.53$
L_3 = 0.005	c_3= \$15.80		
L_4 = 0.01	c_4=\$105.30		

The loss function is given by the following equation:

$$L_{if,1}(x)=\begin{cases} k_1\left[(T-x)^2-(1-a_1)(T-L_2)^2\right] & 1,193,333\left[(0-x)^2-(1-0.53)(0+0.005)^2\right] & L_1\le x\le L_2 \\ k_1a_1(T-x)^2 & (1,193,33\times 0,53)(0-x)^2 & L_2\le x\le T \\ k_2a_2(x-T)^2 & (1,193,33\times 0,53)(x-0)^2 & T\le x\le L_3 \\ k_2\left[(x-T)^2-(1-a_2)(L_3-T)^2\right] & 1,193,333\left[(x-0)^2-(1-0.53)(0.005-0)^2\right] & L_3\le x\le L_4 \end{cases}$$

By assuming a normal distribution for the performance of the key process parameter, with μ = 0 and σ = 0.0025 (1/8 of the total tolerance interval), the expected internal loss can be expressed as:

$$E\left[L_{if,1}\right]=\int_{L_1}^{L_2}L_{if,1}(x)g_{if,1}(x)dx+\int_{L_2}^{T}L_{if,1}(x)g_{if,1}(x)dx+\int_{T}^{L_3}L_{if,1}(x)g_{if,1}(x)dx+\int_{L_3}^{L_4}L_{if,1}(x)g_{if,1}(x)dx$$

where $g_{if,1}(x)$ is $N(\mu,\sigma^2)$. Since both tolerance limits are outside $\pm3\sigma$, the intervals beneath L_1 and above L_4 do not contribute to the loss. The integral is solved by using the approach in Chapter 5.3.1 on page 56, and the expected loss calculated by the Microsoft Excel function described in Appendix G. The expected loss due to one failure is:

$$E\left[L_{if,1}\right]=\underline{\underline{\$4.22}}$$

This loss can be visualized as the area beneath $g_{if,1}(x)$ and $L_{if,1}(x)$ in Figure 6.7.

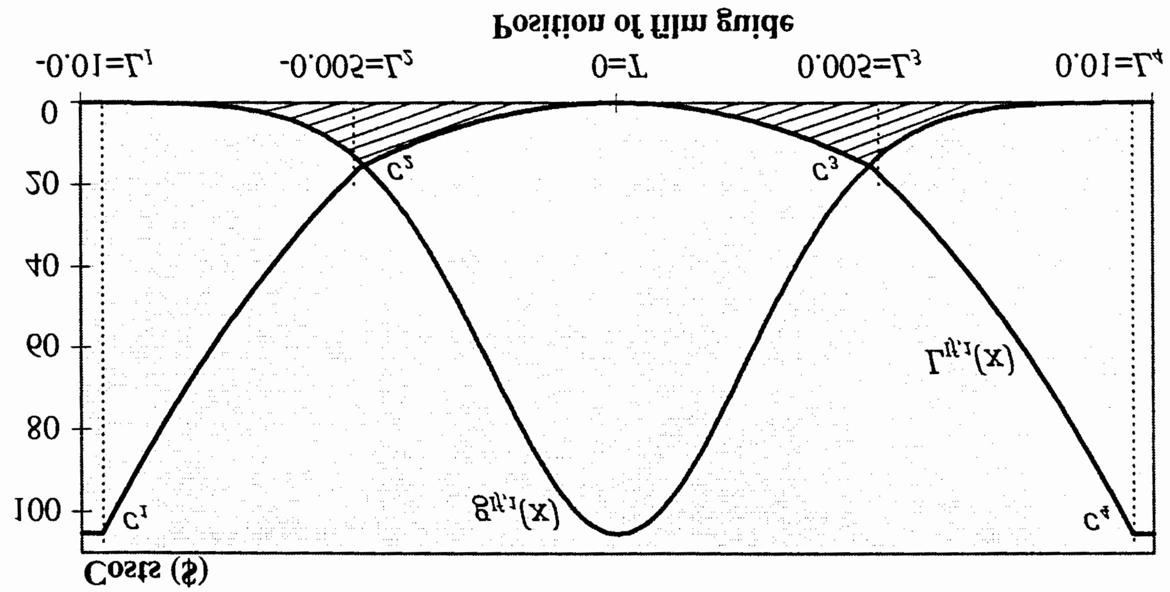


Figure 6.7 Internal Failure Costs, No Film Jams in Processor - Position of Film Guide

Table 6.12 Loss Data for Internal Failure Costs, No Film Jams in Processor - Position of Film Guide

$L_1 = -0.01$	$c_1 = \$105.30$	$k_1 = \dfrac{105.30-15.80}{(0+0.01)^2-(0+0.005)^2} = 1{,}193{,}333$	$a_1 = \dfrac{15.80((0+0.01)^2-(0+0.005)^2)}{(105.30-15.80)(0+0.005)^2} = 0.53$
$L_2 = -0.005$	$c_2 = \$15.80$	$k_2 = \dfrac{105.30-15.80}{(0.01-0)^2-(0.005-0)^2} = 1{,}193{,}333$	$a_2 = \dfrac{15.80((0.01-0)^2-(0.005-0)^2)}{(105.30-15.80)(0.005-0)^2} = 0.53$
$L_3 = 0.005$	$c_3 = \$15.80$		
$L_4 = 0.01$	$c_4 = \$105.30$		

The loss function is given by the following equation:

$$L_{If,1}(x) = \begin{cases} k_1\left[(T-x)^2-(1-a_1)(T-L_2)^2\right] \\ k_1 a_1 (T-x)^2 \\ k_2 a_2 (x-T)^2 \\ k_2\left[(x-T)^2-(1-a_2)(L_3-T)^2\right] \end{cases} \Rightarrow \begin{matrix} 1{,}193{,}333\left[(0-x)^2-(1-0.53)(0+0.005)^2\right] & L_1 \le x \le L_2 \\ (1{,}193{,}33 \times 0{,}53)(0-x)^2 & L_2 \le x \le T \\ (1{,}193{,}33 \times 0{,}53)(x-0)^2 & T \le x \le L_3 \\ 1{,}193{,}333\left[(x-0)^2-(1-0.53)(0.005-0)^2\right] & L_3 \le x \le L_4 \end{matrix}$$

By assuming a normal distribution for the performance of the key process parameter, with μ = 0 and σ = 0.0025 (1/8 of the total tolerance interval), the expected internal loss can be expressed as:

$$E\left[L_{If,1}\right] = \int_{L_1}^{L_2} L_{If,1}(x) g_{If,1}(x)dx + \int_{L_2}^{T} L_{If,1}(x) g_{If,1}(x)dx + \int_{T}^{L_3} L_{If,1}(x) g_{If,1}(x)dx + \int_{L_3}^{L_4} L_{If,1}(x) g_{If,1}(x)dx$$

where $g_{If,1}(x)$ is $N(\mu,\sigma^2)$. Since both tolerance limits are outside $\pm 3\sigma$, the intervals beneath L_1 and above L_4 do not contribute to the loss. The integral is solved by using the approach in Chapter 5.3.1 on page 56, and the expected loss calculated by the Microsoft Excel function described in Appendix G. The expected loss due to one failure is:

$$E\left[L_{If,1}\right] = \underline{\underline{\$4.22}}$$

This loss can be visualized as the area beneath $g_{If,1}(x)$ and $L_{If,1}(x)$ in Figure 6.7.

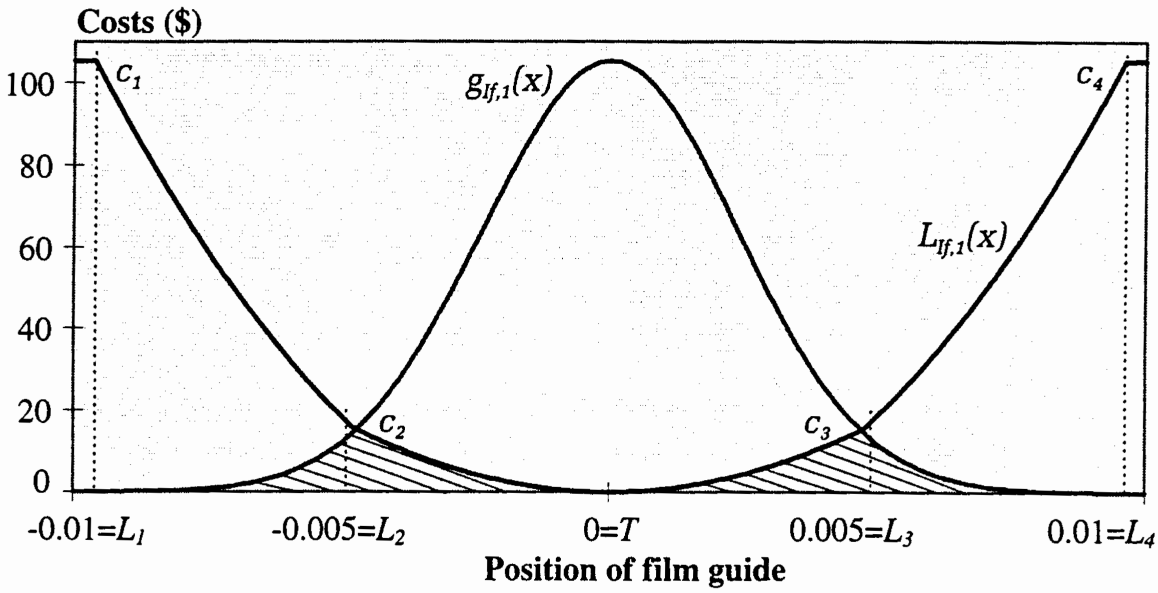


Figure 6.7 Internal Failure Costs, No Film Jams in Processor - Position of Film Guide

❷ Position of rollers

Rollers transfer the film in and between racks. Each of the three racks in the processor consists of 16 rollers of different size. Typical failures that can lead to film jams are unseated rollers, gears that do not mesh, or shafts or bearings that are out of position. As with guide shoes ❶, failures can be detected either at the work station or at setup and testing. The same consequences apply, but due to the number of rollers and their position, the problem solving and repair time will be higher than for ❶.

The loss function is symmetric around the target value (T=0) with one shift. The following characteristics have been used:

Table 6.13 Loss Data for Internal Failure Costs, No Film Jams in Processor - Position of Rollers

L_1=-0.005	c_1=$176.55	$k_1 = \frac{176.55-27.75}{(0.005)^2-(0.002)^2} = 7{,}085{,}714$	$a_1 = \frac{27.75((0.005)^2-(0.002)^2)}{(176.55-27.75)(0.002)^2} = 0.979$
L_2=-0.002	c_2= $27.75	$k_2 = \frac{176.55-27.75}{(0.005)^2-(0.002)^2} = 7{,}085{,}714$	$a_2 = \frac{27.75((0.005)^2-(0.002)^2)}{(176.55-27.75)(0.002)^2} = 0.979$
L_3= 0.002	c_3= $27.75		
L_4= 0.005	c_4=$176.55		

The equation for the loss function is given by:

$$L_{If,2}(x) = \begin{cases} k_1\left[(T-x)^2-(1-a_1)(T-L_2)^2\right] \\ k_1a_1(T-x)^2 \\ k_2a_2(x-T)^2 \\ k_2\left[(x-T)^2-(1-a_2)(L_3-T)^2\right] \end{cases} \Rightarrow \begin{matrix} 7{,}085{,}714\left[(-x)^2-(1-0.979)(0.002)^2\right] & L_1 \le x \le L_2 \\ (7{,}085{,}714\times 0{,}979)(-x)^2 & L_2 \le x \le T \\ (7{,}085{,}714\times 0{,}979)(x)^2 & T \le x \le L_3 \\ 7{,}085{,}714\left[(x)^2-(1-0.979)(0.002)^2\right] & L_3 \le x \le L_4 \end{matrix}$$

By assuming a normal distribution for the performance of the key process parameter, with μ = 0 and σ = 0.00125 (1/8 of the total tolerance interval), the expected internal loss for one failure is: $E\left[L_{If,2}\right] = \underline{\underline{\$10.87}}$

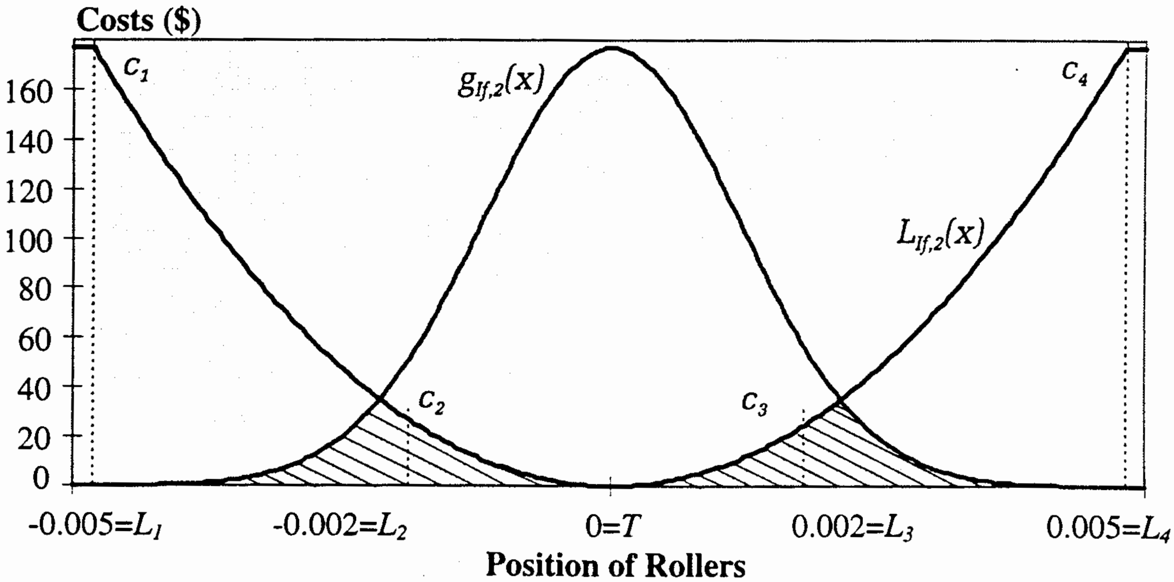


Figure 6.8 Internal Failure Costs, No Film Jams in Processor - Position of Rollers

❸ Position of entrance switch

The entrance switch detects when the film enters the processor. If this switch is out of position, the rollers will start too late or too early, where a too late start may lead to film jam. This result in tighter tolerances on the right side of the target value, and an asymmetric loss function. The inputs to the loss function are:

Table 6.14 Loss Data for Internal Failure Costs, No Film Jams in Processor - Position of Entrance Switch

$L_1 = -0.1$	$c_1 = \$65.50$	$k_1 = \dfrac{65.50 - 14.60}{(0.1)^2 - (0.04)^2} = 6{,}059$	$a_1 = \dfrac{14.60((0+0.1)^2 - (0+0.04)^2)}{(65.50-14.60)(0+0.04)^2} = 1.506$
$L_2 = -0.04$	$c_2 = \$14.60$	$k_2 = \dfrac{65.50 - 14.60}{(0.05)^2 - (0.03)^2} = 31{,}812$	$a_2 = \dfrac{14.60((0.05)^2 - (0.03)^2)}{(65.50-14.60)(0.03)^2} = 0.51$
$L_3 = 0.03$	$c_3 = \$14.60$		
$L_4 = 0.05$	$c_4 = \$65.50$		

The equation for the loss function is given by:

$$L_{If,3}(x) = \begin{cases} k_1\left[(T-x)^2 - (1-a_1)(T-L_2)^2\right] \\ k_1 a_1 (T-x)^2 \\ k_2 a_2 (x-T)^2 \\ k_2\left[(x-T)^2 - (1-a_2)(L_3-T)^2\right] \end{cases} \Rightarrow \begin{matrix} 6{,}059\left[(-x)^2 - (1-1.506)(0.04)^2\right] & L_1 \le x \le L_2 \\ (6{,}059 \times 1.506)(-x)^2 & L_2 \le x \le T \\ (31{,}812 \times 0.51)(x)^2 & T \le x \le L_3 \\ 31{,}812\left[(x)^2 - (1-0.51)(0.03)^2\right] & L_3 \le x \le L_4 \end{matrix}$$

A normal distribution with $\mu = 0$ and $\sigma = 0.01875$ (1/8 of the total tolerance interval) give the expected loss due to one failure as:

$$E\left[L_{If,3}\right] = \underline{\underline{\$4.60}}$$

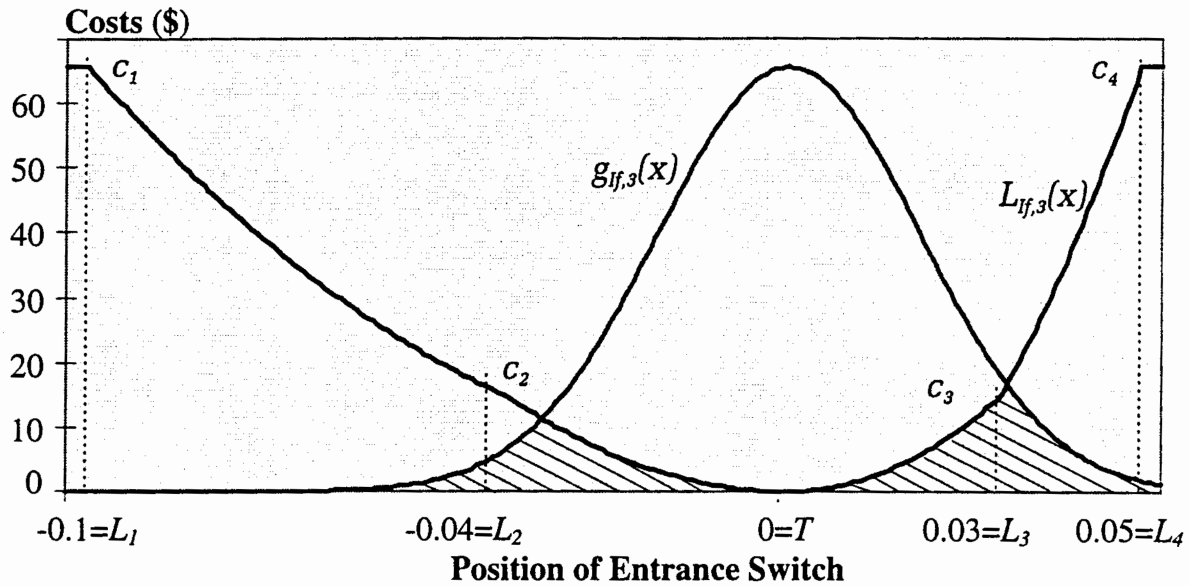


Figure 6.9 Internal Failure Costs, No Film Jams in Processor - Position of Entrance Switch

Overall Internal Cost for Customer Requirement: No Film Jams in Processor (❶+❷+❸)
The expected loss calculated in ❶, ❷, and ❸ occur due to one failure or non-conformance. Each expected losses have been multiplied with the average number of occurrences (*Weight*) during a given time frame to give the total loss for the key process parameter. Weights are based on number of failures reported for one year (Appendix A), which have been divided by 12 to obtain number of failures per month. The horizontal scales of each loss function have

been normalized between -1 and +1 (described in Chapter 5.2.4), and the expected internal failure cost for the customer requirement appears as the sum of the expected failure costs for each key process parameter.

$$L_{If}(x) = L_{If,1}(x) \times Weight(1) + L_{If,2}(x) \times Weight(2) + L_{If,3}(x) \times Weight(3)$$

The performance of each key process parameter is independent, and the overall probability distribution used to visualize the expected loss is the product of each probability distribution.

$$g_{If}(x) = g_{If,1}(x) \times g_{If,2}(x) \times g_{If,3}(x)$$

The monthly internal failure cost for the customer requirement is the sum of the expected failure cost for each key process parameter.

$$E[L_{If}] = \int_{-\infty}^{\infty} L_{If}(x) \times g_{If}(x)dx = E[L_{If,1}] \times Weight(1) + E[L_{If,2}] \times Weight(2) + E[L_{If,3}] \times Weight(3)$$

With the present performance, the overall expected monthly loss due to internal failure costs will be:

$$E[L_{If}] = \$4.22 \times 1.75 + \$10.87 \times 1.50 + \$4.60 \times 0.92 = \underline{\underline{\$27.92}}$$

The approach is described in Figure 6.10 on page 86.

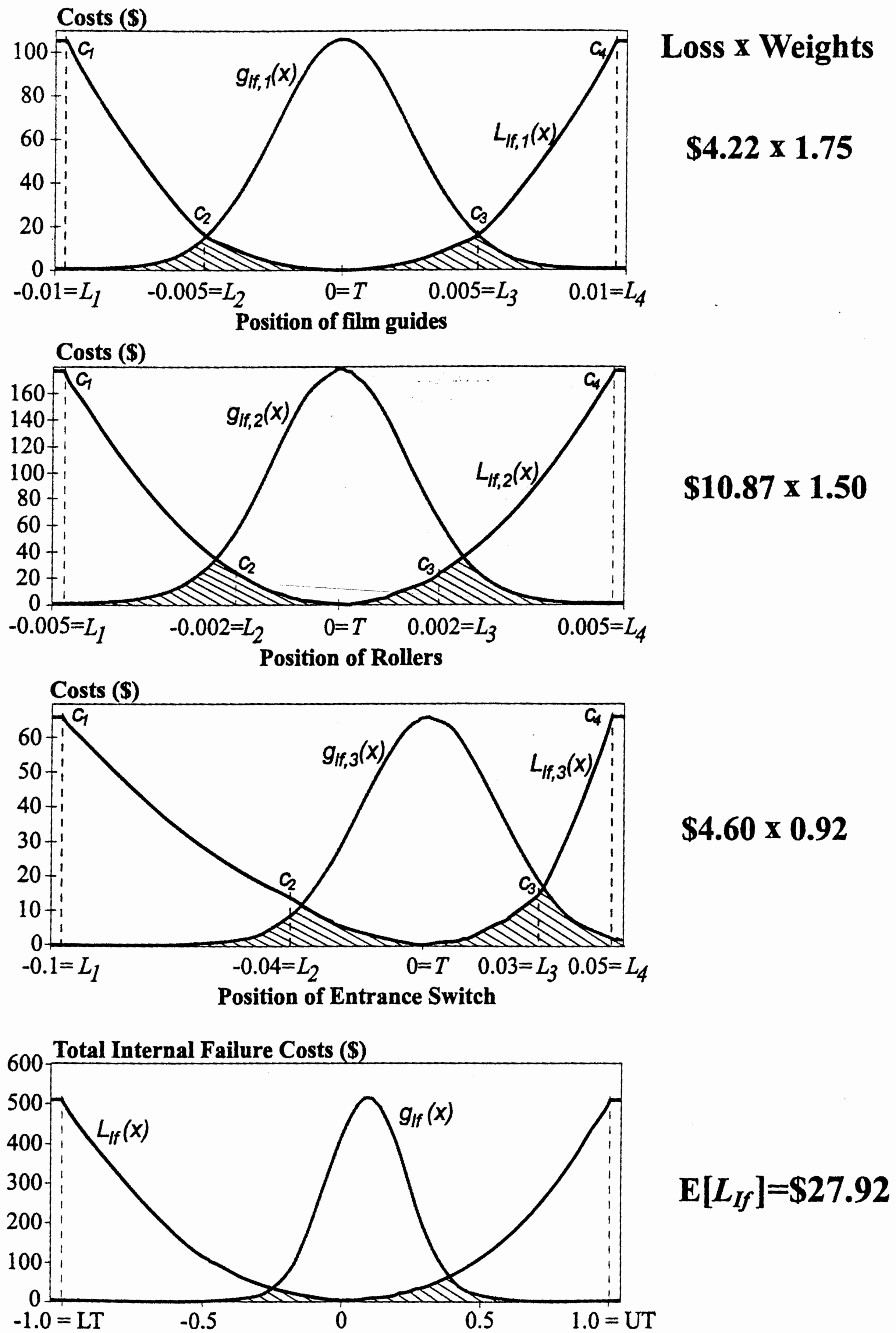


Figure 6.10 Total Montly Internal Failure Costs for Customer Requirement: No Film Jams in Processor

6.3.3 External Failure Costs

External failure costs have been measured directly for the customer requirement, not based on individual key process parameters. Problems resulting in external failure costs will normally occur as a result of a requirement's inability to meet the customer's expectations. The customer will normally not know the cause of the problem (the key process parameter). Shifts in the loss function have been based on the customers perception of when the performance of the requirement changes, the target value in the QFD matrix (❹ in Figure 4.1 on page 33). The evaluation of how the customer requirement is met is based on customer complaint reports (Appendix B). A normal distribution has been assumed, where the monthly average number of complaints for one year has been used as the mean value. There were not enough data to estimate the standard deviation of the number of complaints, and the same standard deviation as estimated for customer incurred costs have been used (Chapter 6.3.4 on page 88).

Customer requirement: No film jams in processor (Appendix F, page 123)
Each shift in the loss function has been based on the customer's perception of how the requirement is met, which is the same as used for customer incurred costs (Chapter 6.3.4, page 88). However, the consequence of not meeting the requirement is different. The first shift in the loss function occurs when the performance gets worse than what is required from the customer (when they are satisfied). This will normally lead to a complaint and consecutive adjustments done by the dealer or Kodak. The next shift occurs when parts have to be replaced, while the last shift involves replacement of the processor.

The loss function represents a smaller-the-better characteristic with three intervals, based on the following parameters:

Table 6.15 Loss Data for External Failure Costs - No Film Jams in Processor

T =	0	c_T =	$0	$k_1 = \frac{829-113}{4^2-1^2} = 47.7$	$a_1 = \frac{113(4^2-1^2)}{(829-113)1^2} = 2.37$
L_1 =	1	c_1 =	$113	$k_2 = \frac{28{,}005-829}{10^2-4^2} = 323.5$	$a_2 = \frac{829(10^2-4^2)}{(28{,}005-829)4^2} = 0.16$
L_2 =	4	c_2 =	$829		
L_3 =	10	c_3 =	$28,005		

The loss function has been defined as:

$$L_{Ef}(x) = \begin{cases} a_1 k_1 x^2 \\ k_1\left[x^2-(1-a_1)L_1^2\right] \\ k_2\left[x^2-(1-a_2)L_2^2\right] \end{cases} \Rightarrow \begin{matrix} (2.37\times 47.7)x^2 \\ 47.7\left[x^2-(1-2.37)1^2\right] \\ 323.5\left[x^2-(1-0.16)4^2\right] \end{matrix} \quad \text{for} \quad \begin{matrix} 0\le x\le L_1 \\ L_1\le x\le L_2 \\ L_2\le x\le L_3 \end{matrix}$$

During one year Kodak had 14 complaints regarding film jams (Appendix B). Divided by 12, this gave a monthly expected number of complaints due to film jams, μ = 1.167. The same standard deviation was used as for customer incurred costs, σ = 0.5 complaints. This is a reliability characteristic and an Exponential or Weibull distribution might be expected, and the solution to the integral obtained by numerical integration. By assuming a normal distribution, the expected loss can be described as:

$$E\left[L_{Ef}\right] = \int_{T=0}^{L_1} L_{Ef}(x)g_{Ef}(x)dx + \int_{L_1}^{L_2} L_{Ef}(x)g_{Ef}(x)dx + \int_{L_2}^{L_3} L_{Ef}(x)g_{Ef}(x)dx + \int_{L_3}^{\infty} L_{Ef}(x)g_{Ef}(x)dx$$

where $g_{Ef}(x)$ is $N(\mu,\sigma^2)$. The integral is solved by using the approach in Chapter 5.3.1, page 56, with the target value $T = 0$. The overall expected loss has been calculated by a Microsoft Excel function described in Appendix G. The integral can be rewritten as:

$$E\left[L_{Ef}\right] = \int_{T^*}^{L_1^*} k_1 a_1\left[(z\sigma+\mu)^2\right] g(z)dz + \int_{L_1^*}^{L_2^*} k_1\left[(z\sigma+\mu)^2 - b_1\right] g(z)dz + \int_{L_2^*}^{L_3^*} k_2\left[(z\sigma+\mu)^2 - b_2\right] g(z)dz$$

where $g(z)$ is $N(0,1)$. The solution to the integral is:

$$E\left[L_{Ef}\right] = k_1 a_1 \mu^2\left[G(z)\right]_{-2}^{0} - k_1 a_1 \mu\sigma\frac{\sqrt{2}}{\sqrt{\pi}}\left[e^{-\frac{1}{2}z^2}\right]_{-2}^{0} + k_1 a_1 \sigma^2\frac{1}{\sqrt{2\pi}}\left[-ze^{-\frac{1}{2}z^2} + \sqrt{2\pi}G(z)\right]_{-2}^{0}$$

$$+ k_1\left[\mu^2 - b_1\right]\left[G(z)\right]_{0}^{6} - k_1 \mu\sigma\frac{\sqrt{2}}{\sqrt{\pi}}\left[e^{-\frac{1}{2}z^2}\right]_{0}^{6} + k_1 \sigma^2\frac{1}{\sqrt{2\pi}}\left[-ze^{-\frac{1}{2}z^2} + \sqrt{2\pi}G(z)\right]_{0}^{6}$$

$$+ k_2\left[\mu^2 - b_2\right]\left[G(z)\right]_{6}^{18} - k_2 \mu\sigma\frac{\sqrt{2}}{\sqrt{\pi}}\left[e^{-\frac{1}{2}z^2}\right]_{6}^{18} + k_2 \sigma^2\frac{1}{\sqrt{2\pi}}\left[-ze^{-\frac{1}{2}z^2} + \sqrt{2\pi}G(z)\right]_{6}^{18}$$

$E\left[L_{Ef}\right] = \$129.20$, which is the expected monthly external PQC.

The intervals beyond L_3 do not contribute to the loss and have been omitted.

$b_1 = (1-a_1)L_1^2$, $\quad b_2 = (1-a_2)L_2^2$, $\quad$ and $\quad L_n^* = \dfrac{L_n - \mu}{\sigma}$

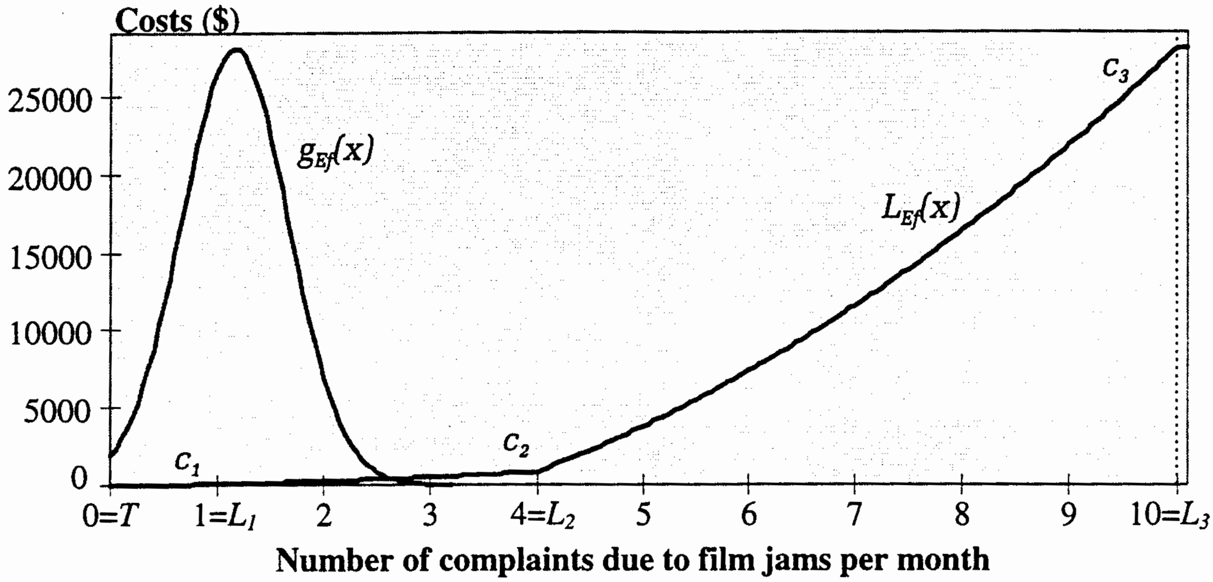


Figure 6.11 External Failure Costs - No Film Jams in Processor

An Exponential or Weibull distribution would probably have given a larger loss since they are skewed towards the right where the loss increases.

6.3.4 Customer Incurred Costs

The 180LP processes approximately 200 films per day, that gives an efficient daily processing time of 1.5 hours (based on throughput time of each film). The purchase cost of the processor is approximately $20,000, and its useful life estimated to 8 years (before major overhaul is necessary). The processor runs 365 days per year. Operating costs (except labor) is estimated to $500 per month. Each film costs about $5 including variable processing costs like power, chemicals, preventive maintenance, etc. Each film jam ruins on average 3 films. Labor costs are based on estimated salary plus overhead. The cost of a patient bed is $1,000 per day.

The 180LP processor is connected to a Kodak Ektascan 2180 laser printer which is also put out of service when the processor stops. The purchasing cost of the laser printer is approximately $80,000. Operating costs have not been evaluated for this device since this is not the prime target for this analysis, but it should be included in a complete analysis.

Processor cost per hour:		
$20,000/(8 years x 365 days x 1.5 hours)	=	$4.60
$500 per month/(30days x 1.5 hours)	=	$11.10
Total per hour	=	$15.70

Printer costs per hour:		
$80,000/(8 years x 365 days x 1.5 hours)	=	$18.30
Total cost per hour	=	$18.30

The total cost is for one failure, and costs are driven by number of film jams (cost driver).

Customer requirement: No film jams in processor (Appendix F, page 124)
The loss function is of the type smaller-the-better with three shifts. Customer satisfaction is obtained when there is no more than one film jam per month resulting in a stop less than 30 minutes. The second shift arises when there are more than four film jams per month due to a need of more thorough analysis of the problem, and possible remodeling of some parts of the processor. This extra effort is estimated to six hours (service technician + downtime for processor and printer). If more than ten film jams occur every month the processor is not usable any more, and would have to be replaced. Replacement costs are set to 50% of purchasing costs.

Table 6.16 Loss Data for Customer Incurred Costs - No Film Jams in Processor

T= 0	c_T =	$0	$k_1 = \frac{1,190-209}{4^2-1^2} =$ 65.4	$a_1 = \frac{209(4^2-1^2)}{(1,190-209)1^2} =$ 3.20
L_1 = 1	c_1 = 1x209 =	$209	$k_2 = \frac{12,090-1,190}{10^2-4^2} =$ 129.8	$a_2 = \frac{1,190(10^2-4^2)}{(12,090-1,190)4^2} =$ 0.57
L_2 = 4	c_2 = 4x209 + 6(25 + 15.7 + 18.3) =	$1,190		
L_3 = 10	c_3 = 10x209 + 0.5x20,000 =	$12,090		

The loss function is given by:

$$L_{Ci}(x) = \begin{cases} a_1 k_1 x^2 \\ k_1\left[x^2-(1-a_1)L_1^2\right] \\ k_2\left[x^2-(1-a_2)L_2^2\right] \end{cases} \Rightarrow \begin{matrix} (3.20\times 65.4)x^2 \\ 65.4\left[x^2-(1-3.20)1^2\right] \\ 129.8\left[x^2-(1-0.57)4^2\right] \end{matrix} \quad \text{for} \quad \begin{matrix} 0 \le x \le L_1 \\ L_1 \le x \le L_2 \\ L_2 \le x \le L_3 \end{matrix}$$

Performance data indicating how often film jams occur, and their extent, were not obtainable from the hospital. The mean value and standard deviation used is based on a qualified guess by the service technicians at the hospital. A normal distribution is assumed with μ = 1.0 film jams per month, and $\sigma = 0.5$ film jam. The same approach applies as for external failure costs, giving the expected monthly customer incurred PQC:

$$E\left[L_{Ci}\right] = \underline{\underline{\$185.70}}$$

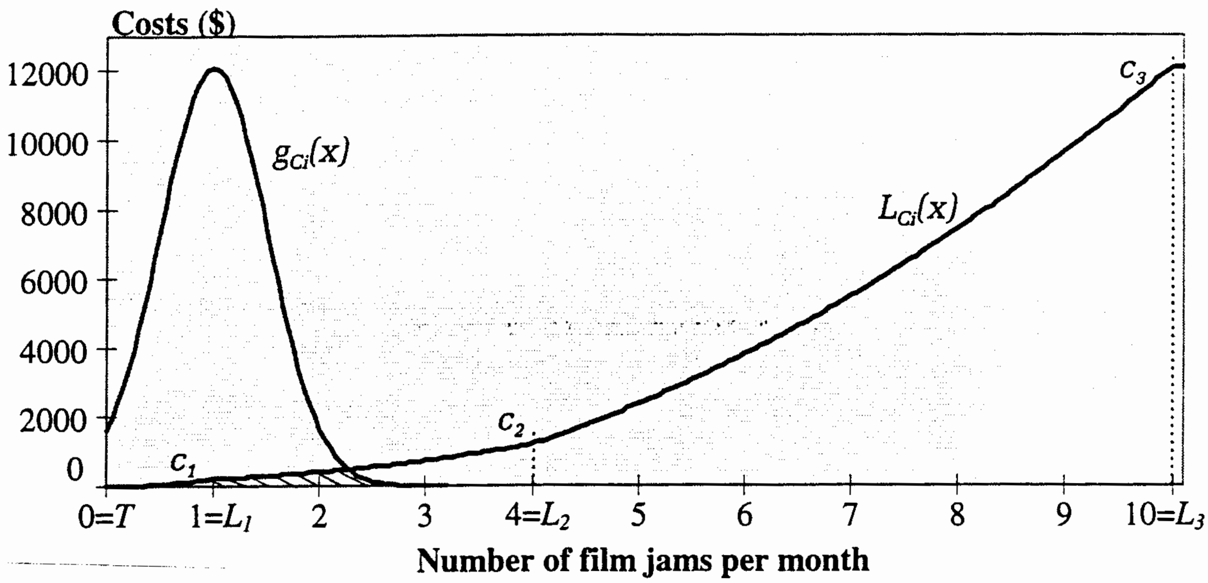


Figure 6.12 Customer Incurred PQCs - No Film Jams in Processor

As for external failure costs, an Exponential or Weibull distribution would probably have resulted in a larger loss.

6.3.5 Environmental Costs

Environmental costs have not been calculated for any customer requirements. The methodology for measuring environmental costs has not been developed, and are left as suggestions for further research.

6.3.6 Lack of Process Efficiency Costs

This element has not been estimated since it requires a full scale benchmarking study. Kodak have not done any benchmarking for the key process parameters of current interest, and the cross functional team did not feel competent to make any qualified guesses. The approach is briefly described in Chapter 3.1.3.

6.4 INTANGIBLE COSTS

Measures of intangible costs are based on Strong Memorial Hospital and S&W X-ray's rating of importance of each customer requirement (❸ in Figure 4.1), Kodak's performance compared to chief competitor (❻ in Figure 4.1), and an estimate of the potential loss due to loosing Strong Memorial Hospital as a customer. A more thorough description of the approach can be found in Chapter 4.7 on page 42.

6.4.1 Estimate of Potential Loss

The overall intangible loss (C_{tot}) due to the possible loss of Strong Memorial Hospital as a customer, both for the 180LP processor and other Kodak products, has been estimated based on information from the hospital and Kodak Health Imaging. The loss consists of three parts that have to be estimated individually.

① An estimate of lost sales for the 180LP if Strong Memorial Hospital is lost as a customer. At present they have 23 processors in service, of which 3 are 180LPs. The expected useful lifetime of each is estimated to 12 years (8 years before major overhaul and then 4 more years before they have to be replaced). This gives an annual repurchase need of 1.9 processors. The 180LP is a new processor that accommodates most of the needs at the hospital, and it is assumed that 50% of new purchases will be 180LPs. This gives an annually expected repurchase intention of 0.96 180LPs. With a selling price of $20,000, the expected annual loss is $19,200.

② Strong Memorial Hospital is one of two major hospitals in the Rochester areas, and the city is mainly divided in two sections with one major hospital in each. In addition there are several smaller hospitals in each section. A discontinued use of the 180LP processor at Strong would most likely strongly effect the smaller hospitals in their area, and to a lesser degree other hospitals. Kodak sells approximately five 180LP processors each year in the Rochester area, and it is estimated that the sale of two additional units would be lost if Strong advised against the product. No effect is expected outside the local market. The expected loss will be 2 x $20,000 = $40,000.

③ This part estimates the effect not purchasing the 180LP will have on other Kodak products that are presently used at Strong Memorial Hospital. Some products like the printer, film, spare parts, and chemicals are directly linked to the processor, and would for certain be influenced by a discontinued use of the processor. Another aspect is the effect on the overall purchase strategy at the hospital. If they bought a competing processor for the specific task done by the 180LP, and were very satisfied with it, they may change every processor (and completive components) over time to obtain a uniform equipment basis.

Table 6.17 Estimated Effect on Other Products due to Loosing Strong Memorial Hospital as a Customer

Component	**Basis of Calculation**	**Estimate**	**Cost**
2180 Printer	Purchase cost times repurchase (same as for printer)	$80,000 x 0.96	$76,800
Film and chemicals	200 films per day x 365 days x $3 (film + chemicals)	200 x 365 x $3	$219,000
Spare parts	Estimated to $2,000 per year.	1 x $2,000	$2,000
Other processors	10% chance of alternation, same cost as for 180LP	0.1 x $20,000 x 0.96	$1,920
Additional film and chemicals	200 films used as daily average for every other processor (22). 10% chance of change.	0.1 x 200 x 365 x 22 x $3	$481,800
Additional spare parts	22 processors x same costs as for 180LP x 10% ch.	0.1 x 22 x $2,000	$4,400
Non related products	No effect is anticipated.		$0
Total for ③			$803,200

The overall loss can then be estimated as:

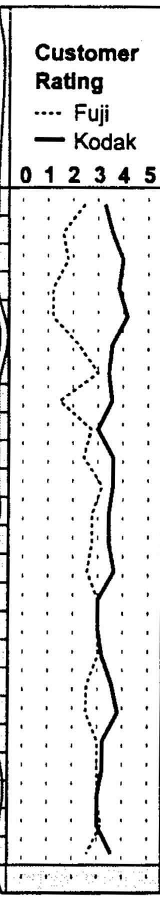
	①	$19,200
	+ ②	$40,000
	+ ③	$803,200
	$= C_{tot}$	$862,400

This is the overall estimated *annual* intangible costs due to the loss of Strong Memorial Hospital as a customer.

6.4.2 Performance Evaluation, Cost Index, and Estimated Loss

The QFD matrix (Figure 6.5, page 79) reveals that the performance of the 180LP is rated better or equal to the chief competitor for every customer requirement but one. This requirement has a low attached importance, and the difference in performance is minimal. An expected intangible loss would be minimal. In this section the performance of the chief competitor has been displaced by one unit to demonstrate the approach used to measure intangible costs.

WHATs (HOWs are not included to save space)	Importance (I_i)	Performance (P_i)	Cost Index (CI_i)	⇒	Importance (I_i)	Performance (P_i)	Cost Index (CI_i)
1 Fast and timely first time delivery of pros. and comp.	5.7	-0.9	0.00		5.7	0.1	0.57
2 Easy access to interior of processor	3.2	-2.0	0.00		3.2	-1.0	0.00
3 Easy to diagnose and troubleshoot problems	3.7	-2.2	0.00		3.7	-1.2	0.00
4 Possible to replace parts without moving other comp.	3.0	-2.6	0.00		3.0	-1.6	0.00
5 Spare parts always available when needed	3.4	-3.0	0.00		3.4	-2.0	0.00
6 Fast recovery after problems and stops	7.7	-1.4	0.00		7.7	-1.4	0.00
7 Long time between failures and stops	7.0	-0.4	0.00		7.0	0.6	4.20
8 Easy to replace components	2.9	-2.2	0.00		2.9	-1.2	0.00
9 Pros. operates min. 8 years before major overhaul	4.7	-0.3	0.00		4.7	0.7	3.29
10 Possible to upgrade major comp. and add features	5.3	-1.2	0.00		5.3	-0.2	0.00
11 The processor have a small footprint	0.7	-0.4	0.00		0.7	0.6	0.42
12 Easy connection of plumbing	2.6	-0.6	0.00		2.6	0.4	1.04
13 Hoses out of the way	0.6	-0.6	0.00		0.6	0.4	0.24
14 Fast and easy to fill chemicals	2.7	-1.0	0.00		2.7	0.0	0.00
15 Low purchasing costs	2.9	0.0	0.00		2.9	1.0	2.90
16 Low operating costs	3.0	0.0	0.00		3.0	1.0	3.00
17 No film jams in processor	8.3	-0.2	0.00		8.3	0.8	6.64
18 Pros. able to minimize consequences of film jam	7.9	-1.0	0.00		7.9	0.0	0.00
19 Processor able to prevent film mix-up (feature)	4.3	-1.3	0.00		4.3	-0.3	0.00
20 No leaks of chemicals	7.2	-0.2	0.00		7.2	0.8	5.76
21 No external pollution from processor	4.1	-0.2	0.00		4.1	0.8	3.28
22 Processor take care of silver (feature)	2.2	0.0	0.00		2.2	1.0	2.20
23 Low noise level	3.8	0.2	0.76		3.8	1.2	4.56
24 High processing speed	4.9	-1.0	0.00		4.9	0.0	0.00
Basic Requirements (see App A and App B)	ΣI_i=101.8		ΣCI_i=0.76		ΣI_i=101.8		ΣCI_i=38.1



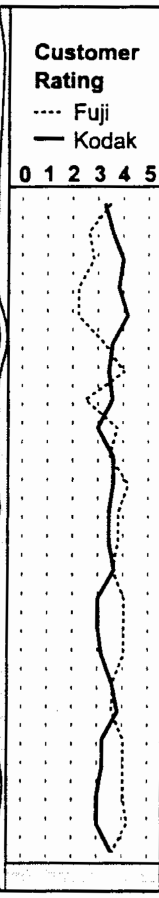


Figure 6.13 Transformed Performance used to Calculate Intangible Costs

The following elements have been used in the loss calculation:

I_i = Importance attached to requirement i (this is the weighted importance calculated in Chapter 6.1.5).

P_i = The company's performance for requirement i where a *negative* P_i indicates better performance than the chief competitor (described in Chapter 6.1.6).

$CI_i = I_i \times P_i$ (Cost index for requirement *i*).

$CI_{i,\max} = I_i \times 5$ equals worst case difference in performance ($P_i = 5$).

A loss factor (f_{loss}) can be described as the overall loss estimated in ①, ②, and ③ (C_{tot}) divided by the worst case cost index (Ci_{max}), that is when the difference in performance is five for every requirement to the disadvantage of Kodak:

$$f_{loss} = \frac{C_{tot}}{CI_{max}} = \frac{C_{tot}}{5 \times \sum_{i=1}^{n} I_i} = \frac{\$862{,}400}{5 \times 101.8} = 1{,}694$$

The expected *annual* intangible PQC for the 180LP processor, using the displaced performance in Table 6.13, can be estimated as the loss factor (f_{loss}) times the sum of actual cost indexes (CI_i).

$$E[L_{In}] = f_{loss} \times \sum_{i=1}^{n} CI_i = 1{,}694 \times 38.1 = \underline{\underline{\$64{,}553}}$$

The actual data from the survey gives a total *annual* intangible PQC of:

$E[L_{In}]_{Annual} = 1{,}694 \times 0.76 = \underline{\underline{\$1{,}288}}$, that gives a monthly intangible PQC of:

$$E[L_{In}]_{Month} = \$1{,}288 / 12 = \underline{\underline{\$107.30}}$$

This represents the *monthly* expected intangible PQC for the 180LP processor based on the total loss (C_{tot}) that is expressed as lost revenue due to the loss of Strong Memorial Hospital as a customer ①, lost revenue due other hospitals that refrain from buying the product ②, and lost revenue due to lost sales of other products provided by Kodak ③. The expected loss result from the total loss (C_{tot}) and the probability that a loss will occur (ΣCI_i), which is determined by the company's performance (P_i) and the customer's stated importance for each requirement (P_i). This approach makes it possible to focus improvement activities to yield maximum benefit for the customer and obtain an optimal reduction of intangible PQCs.

6.4.3 Overall Expected Poor Quality Costs for the Customer Requirement

Every cost element in the new customer and process focused poor quality cost model (Figure 3.1 on page 23, and Figure 3.2 on page 24), except lack of process efficiency costs and environmental costs, have been calculated. The total monthly expected poor quality cost for customer requirement number 17, no film jams in processor, is calculated as the sum of each cost element described in previous chapters.

Table 6.18 Overall Poor Quality Costs for Customer Requirement

Direct poor quality costs	
Internal poor quality costs (Chapter 6.3.2)	$ 27.92
External poor quality costs (Chapter 6.3.3)	$ 129.20
Indirect poor quality costs	
Customer incurred costs (Chapter 6.3.4)	$ 185.80
Intangible costs (losses) (Chapter 6.4.2)	$ 107.30
Environmental costs	$ N/A
Total poor quality costs	$ 450.22

Consequence costs have been accounted for in the loss function with the aid of the simplified Activity Based Costing approach. Lack of process efficiency costs have not been included, but would have been linked to internal and external failure costs as explained in Figure 3.1 on page 23.

Total poor quality costs represent the loss Kodak can expect based on insufficient process performance that influence the fulfillment of *one* customer requirement. Every customer requirement in the QFD matrix (Figure 6.5) have to be addressed to obtain a complete picture of poor quality costs for the product.

The result in Table 6.18 support the hypothesis that it is not adequate to rely on the approach of traditional quality cost models, that is primarily focused on internal failure costs. External PQCs far exceeds internal PQC, and indirect PQCs are larger than direct PQCs. Priorities for improvement will probably change if this model were used compared to a traditional approach.

7. SUMMARY

Traditional quality cost systems are mainly internally company focused and reactive by nature. Improvement activities are prioritized according to internal measures and negative feedback from the customer after problems have occurred, which may lead to sub-optimization of processes not always beneficial to the customer. Performance measurement and top management decisions are usually based on traditional accounting information which is often inadequate to monitor and direct quality improvement activities.

A new customer and process focused PQC model has been proposed to overcome some of the problems with traditional quality cost measurement. The appraisal and prevention elements have been left out, since they are difficult to measure and/or have limited application in the strategic decision-making process. Non-critical failure costs, being costs due to failures that will not affect the fulfillment of customer requirements, have not been emphasized since they are covered by traditional quality cost systems. Both appraisal costs, prevention costs, and non-critical failure costs should still be measured for internal operational use in each department.

The new PQC model is based on customer requirements, needs, and expectations and utilizes the QFD matrix to translate the voice of the customer to measurable and controllable process characteristics. Taguchi's loss function has been used to estimate expected PQCs for critical internal, critical external, customer incurred, and environmental costs. Critical internal failure costs are estimated based on key process parameters that influence the fulfillment of customer requirements, while the other cost elements are based directly on how each customer requirement is met. A simplified Activity Based Costing approach has been used along with actual process performance to calculate expected losses for each of the four elements. An approach of estimating intangible costs have also been provided based on the use of the QFD matrix.

The new PQC model was tested and verified in cooperation with Kodak Health Imaging, Strong Memorial Hospital, and S&W X-ray in Rochester New York. Correspondence analysis revealed that weighting the importance of customer requirements solely based on customer groups and their importance is inadequate. User groups and their influence on the purchase and re-purchase decision have to be considered as well. The overall importance of each customer requirement has to be calculated as the average importance within each user group multiplied by the weight of the group, and then summarized for each customer requirement. Analyzing the data from the pilot study through correspondence analysis also reveals which questions that are appropriate for each user group. The questionnaire used in the main survey should be customized to each user group, including only requirements that are suitable to the group.

Production and customer complaint data have been translated to customer requirements. This provided basic customer information in addition to being a check list for basic requirements in the QFD matrix. Customer complaints usually reflect basic requirements that are unfulfilled and will lead to dissatisfaction if they are allowed to occur.

The customers' rating of importance and their evaluation of how the manufacturer meets their expectations compared to competing suppliers (the performance) has been used to calculate a cost index for each requirement. This index has been used to calculate intangible costs, and it can also be used to prioritize which requirements to measure, analyze, and improve first. Every company has limited resources, and every customer requirement cannot be included in the analysis simultaneously. The cost index enables the company to focus on requirements that are most important to their customers, and where the company's performance is inadequate compared to chief competitors.

A simple methodology for gathering cost data and analyze processes has been provided. The approach provides a perspicuous way of breaking down processes into activities that consume resources, and serve as a simplified Activity Based Costing approach. Complete data required to construct loss functions have been gathered in one form, minimizing the necessary resource consumption.

Internal failure costs have been measured based on key process parameters that have been summarized for each customer requirement, while external failure costs and customer incurred costs have been measured directly based on customer requirements. Each loss function has been linked to actual process performance, enabling the manufacturer to visualize how improvement activities will influence overall PQCs. The manufacturer can use the model to simulate how changes in process performance will affect PQCs by changing the target value or the variation of the performance.

Intangible costs have been made less intangible through an approach that breaks down costs to manageable elements and links them to actual process performance through the QFD matrix. A cost index has been used to disperse overall intangible costs to individual customer requirements enabling the manufacturer to set priorities for improvement.

The case study revealed that external PQCs are larger than internal PQCs, at the same time as total indirect PQCs are larger than total direct PQCs. This sustains the supposition that relying solely on internal failure costs, and negative feedback from the customer as feedback for quality improvement decisions is inadequate. Costs have to be measured based on customers' evaluation of performance to reflect customer satisfaction and loyalty. Priorities for improvement will most likely change considerably when the voice of the customer is included in the cost analysis. An allegation is that companies that rely exclusively on traditional quality cost models are sub-optimizing their processes, and the results of quality improvement may at worst antagonize customer satisfaction and loyalty.

8. IMPLEMENTATION OF THE NEW PQC MODEL AND FURTHER RESEARCH

Developing a complete implementation strategy for the new PQC model is beyond the scope of this work, but some general thoughts are presented based on experiences from the case study at Kodak Health Imaging.

The main elements of the new PQC model should already be present in a fully developed world class organization. Market surveys and analyses are used as basis for product development, and Quality Function Deployment is used to translate requirement to production specifications (Figure 4.2). Processes should be controlled through tolerance design (Taguchi), and the accounting system should be based on Activity Based Costing. If these conditions are met, it should be possible to implement the PQC model by redefining existing data, and the extent of the implementation process should be limited.

On the other hand, if the main elements do not exist, the effort will be considerable. A comprehensive market study and a full scale use of Quality Function Deployment require an extensive use of resources. Activity Based Costing and tolerance design involve a total redesign of how companies conduct their financial and process control. However, it is the author's belief that these elements are requirements, not options, for a company of the future. If a company is going to survive in today's increasingly tough environment, it has to adapt to new techniques and approaches of managing the company. Only world class manufacturers will survive in the international marketplace.

Another limitation in the implementation process is that every company has limited resources and cannot work on every requirement simultaneously. The model addresses this problem by prioritizing the most important problem first. This is done in several steps. First, each customer requirement is ranked through the rating of importance, and the manufacturer can focus on the most important requirement. Second, each key process parameter is also ranked in the body of the QFD matrix (Figure 6.5). Only key process parameters that strongly influence how the customer requirement is met should be improved at first if it is impossible to address every key process parameter at the same time. Third, each loss function clearly indicates for which cost category the loss is most severe, and thereby which processes that should be improved to reduce the overall loss. The model enables the manufacturer to prioritize and improve processes to maximize the benefit of the customer and thereby increase customer satisfaction and loyalty by minimal resources.

The new customer and process focused poor quality cost model is not complete. It provides an overview of a new approach that is aimed at providing more accurate information for strategic management decisions based on actual costs of not fulfilling customer requirements. Several elements are not described completely and some work remains before the model can be fully utilized. Elements that will improve the model's analytical capabilities are:

1. The method of measuring lack of process efficiency costs has not been verified since it requires a full scale benchmarking study. These costs are very important, especially when companies are transforming to lean production systems where process efficiency is the key element. Measuring lack of process efficiency costs enables the manufacturer to focus on waste even if it does not directly influence how customer requirements are met. This

element is not the same as non-critical failure costs (Chapter 3.1.1). A product can be produced failure free, but still bring about lack of process efficiency costs. This element reflects the deviation in performance standard compared to competitors.

2. The methodology of measuring environmental costs has not been developed. However, the importance of this element will only increase in the future as customers get more environment-conscious, new environmental standards evolve (like the ISO 14000 series), and government regulations tighten. This element should be further developed and integrated in the model.
3. The model is suitable for simulation. Basic simulations can be done through the Excel function described in Appendix G, where changing the target value or variability returns a reduced or increased loss. A more integrated simulation model that embraces every key process parameter and customer requirement for every cost element would be a powerful decision-making tool for top management. The simulation model should reflect how variation in key process parameters influences the overall loss.
4. Design of experiments (DEO) may be used to increase the accuracy in the process of identifying key process parameters and their influence on the fulfillment of customer requirements. A full scale implementation of the model will result in a large number of key process parameters and design of experiments will make the analysis more manageable.
5. The model represents an upper level approach to tolerance design. In order to obtain process improvements and world class manufacturing, the model should be linked to lower level tolerance design. The model represents a measurement tool that can be utilized when lower level tolerances are determined for each key process parameter. The approach has been briefly described in Chapter 5.5, but a more thorough exploration remains.
6. The accuracy of PQC data is not of great importance since they show the relative cost difference of not meeting customer requirements. The cost of a few requirements will normally rise as most important, and the prioritization will be evident. However, a methodology of determining the precision or confidence interval of the cost data would have improved the model, especially in those situations where PQC data have to compete with traditional accounting information. To determine how accurate the data are have not been emphasized in this work.

Some of these elements may be topics for new Ph.D. dissertations, while others have to be addressed during the practical implementation of the model.

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APPENDIX A - CUSTOMER REQUIREMENTS TRANSLATED FROM MANUFACTURING PROBLEMS

These customer requirements have been translated from one year of internal production data and failure reports. They are all basic requirements according to Kano's model, and serve as a checklist for the QFD matrix (Figure 6.5 on page 79).

Translated Requirement	Failures
1. Labeling is correctly applied and possible to understand and use.	Wrong labeling Damaged labeling Missing labeling Wrongly applied labeling Silk screening flakes off
2. All necessary parts are included and correctly installed	Missing E-ring Missing O-ring Missing spring Missing washer Missing harness bracket Missing cable bracket Missing guide shoe Missing magnetic switch Loose screws Not glued Loose cord coupling Circuit breaker upside down Pumps wrongly hooked up Hoses wrongly installed Wrong spring tension on door Wires not seated Electric components not seated Gear not lined up with chain Drive chain too tight Loose clamps
3. Every component is in working order and suitable for use	Part not painted Paint wipes off Gear end chewed up Unit do not fit frame Wrong paint Spot on roll Nick on roll Broken flange Broken gudgeon Rust/corrosion Threads damaged Tube is torn Leveling screw holes filled
4. Correct parts have been installed	Wrong guide shoes Parts interfere (long screws) Wrong shafts

5. Every part fits	Missing holes Threads are fouled Wrong placing of holes Brackets in wrong place Rolls have uneven diameter Warped rollers
6. Exterior is undamaged and have a nice appearance	Scratches Polish marks Weld spots Dents Marks Frame not washed off Insulation is sticking Tube is dirty Spill from chemicals Cover is dirty Masking not removed
7. Processor works according to requirements	Replenish Button don't work Adjustment impossible Pump leak Switches in wrong position Switches not working Motor not turning Circuit breaker fails Noise Defective solenoid Defective circuit breaker Software failure Back splash from wash rack Blower not operating Heater do not work Pump do not work Leaks 500 board do not work Sensors do not work Hinges do not work or fit
8. Packaging is undamaged and correct	Labeled as another model Carton is damaged Carton is dirty Cleaning/replace Rolls are improperly packed
9. Documentation is included and complete	Damaged documentation
10. Processor provides required results	Scratches on film

APPENDIX B - CUSTOMER REQUIREMENTS TRANSLATED FROM CUSTOMER COMPLAINTS

Based on:
- Customer equipment service (outside US)
- Customer/dealer phone calls (800 line)
- Internal testing (samples)
- Meetings with customers and other kind of customer feedback
- Returned service parts failure analysis

Translated requirements based on failures are either satisfiers (S) from the requirement list in the QFD matrix (Figure 6.5 on page 79), or basic requirements (B) from Appendix A.

Translated Requirement	Failures	# Complaints (one year)	
1. Long time between failures and stops (S7)	High failure rate in power supply	31	**38**
	Dryer assembly bearing worn out	2	
	Drive motor was leaking oil	1	
	Corrosion in multiloader	1	
	Early deterioration of silicon rollers	1	
	Premature bearing wear of the wash rack	1	
	Rusting dryer sprocket	1	
2. No leaks of chemicals (S20)	Chemicals leaking into rollers	2	**6**
	Developer leak at clamp	3	
	Solution leaks	1	
3. Low noise level (S23)	Noisy fan on sorter kit	1	**4**
	Pump clunks	3	
4. All parts included and correctly installed (B2)	Parts missing from 180 pre-pack	1	**11**
	Connector on 500 board not seated	1	
	Power supply not connected properly	1	
	Film detector switch out of adjustment	5	
	Wash chain too lose	1	
	Dole valve installed backwards	1	
	Wire insulation was cut	1	
5. Every component is in working order and suitable for use (B3)	Debris in air-tube causes dryer artifact	1	**4**
	Wash rack guide shoes difficult to orient	1	
	Switch jumps out of housing	1	
	Leveling screw had to be tapped	1	
6. Correct parts have been installed (B4)	Wrong screw on blower mount bracket	1	**1**
7. Exterior is undamaged and have a nice appearance (B6)	Cracked cover	1	**1**
8. Processor works according to requirements (B7)	Wash water diluting fix	16	**22**
	Sorter motor not engaging	1	
	Water selenoid does not shut water off	2	
	Sorter kit not sensing film	1	
	Temperature in developer too high	2	
9. Documentation included and complete (B9)	Manual not correct	4	**5**
	Confusing installation instructions (sorter)	1	
10. Processor provides required result (B10)	Guide shoe scratches on film	5	**6**
	Film artifacts	1	

APPENDIX C - QUESTIONNAIRE USED TO OBTAIN CUSTOMER INFORMATION

This questionnaire were used at Strong Memorial Hospital, S&W X-ray, and the Marketing Department at Eastman Kodak Company's Health Imaging Division to obtain customer information in addition to the requirements identified in the focus group. The questionnaire consisted of a cover letter and four pages of questions.

September 27, 1996

Dear Name,

I am a Norwegian research scholar staying at RIT for one year working on my Ph.D. within quality cost measurement. Strong Memorial Hospital and Eastman Kodak Company Health Imaging are helping me in the project by providing the necessary data.

The 180LP x-ray film processor has been chosen for this project. This processor is presently used in the CT and Special Ward and is connected to a laser printer. A group from different areas at Strong Memorial Hospital has identified the hospital's requirements, needs, and expectations to the processor. In addition to this, we need help from you to determine how important each requirement is and how the processor performs compared to your expectations.

The data will be used to identify how Kodak Health Imaging can improve their internal processes to improve your satisfaction with the 180LP processor. The form will only be used by me and destroyed when the data have been processed. I hope you do not mind if I get in touch with you in case clarification is necessary.

Your help is highly appreciated and crucial for the outcome of my project. *Please be as complete as possible and provide comments. Use the reverse side of the page if necessary.* I need as complete data as possible to understand your needs. If something is unintelligible, please give me a call at 475-2442 or send me an E-mail at RMMEQA@RIT.EDU. Please return the completed form to Joe Orlando.

In advance, thank you very much!

Yours sincerely,

Rune Moen

Enclosures.

a) Where do you work?
❑ Strong Memorial Hospital ❑ S&W X-ray ❑ Eastman Kodak Company

b) What is your job function?
❑ Service technician ❑ Clinical technician ❑ Administration ❑ Technical supervision
❑ Radiologist ❑ Marketing ❑ Sales ❑ Other ______________

c) How often are you involved with the processor?
❑ Daily ❑ Weekly ❑ Monthly ❑ Annually ❑ Never

d) How many years experience do you have in a X-ray department or with X-ray processors? __________

e) How much time do you use in connection with the 180LP processor? Please try to make an estimate of minutes per day/week/month (as indicated in **c**): ______________________________

PART I Absolute importance of each requirement

Please indicate the importance of each requirement according to **YOUR** needs on a scale from 1 to 9 where 1 is *totally unimportant* and 9 is *critical*.

	Unimportant 1	2	3	4	5	6	7	8	Critical 9
1. Fast and timely first time delivery of processor and components	❑	❑	❑	❑	❑	❑	❑	❑	❑
2. Easy access to the interior of the processor	❑	❑	❑	❑	❑	❑	❑	❑	❑
3. Easy to diagnose and troubleshoot problems	❑	❑	❑	❑	❑	❑	❑	❑	❑
4. Possible to replace parts without removing other components	❑	❑	❑	❑	❑	❑	❑	❑	❑
5. Spare parts always available when needed	❑	❑	❑	❑	❑	❑	❑	❑	❑
6. Fast recovery after problems and stops	❑	❑	❑	❑	❑	❑	❑	❑	❑
7. Long time between failures and stops	❑	❑	❑	❑	❑	❑	❑	❑	❑
8. Easy to replace components	❑	❑	❑	❑	❑	❑	❑	❑	❑
9. The processor operates minimum 8 years before major overhaul	❑	❑	❑	❑	❑	❑	❑	❑	❑
10. Possible to upgrade major components and add new features	❑	❑	❑	❑	❑	❑	❑	❑	❑
11. The processor has a small foot print	❑	❑	❑	❑	❑	❑	❑	❑	❑
12. Easy connection of plumbing	❑	❑	❑	❑	❑	❑	❑	❑	❑
13. Hoses out of the way	❑	❑	❑	❑	❑	❑	❑	❑	❑
14. Fast and easy to fill chemicals	❑	❑	❑	❑	❑	❑	❑	❑	❑
15. Low purchasing costs	❑	❑	❑	❑	❑	❑	❑	❑	❑
16. Low operating costs	❑	❑	❑	❑	❑	❑	❑	❑	❑
17. No film jams in processor	❑	❑	❑	❑	❑	❑	❑	❑	❑
18. Processor able to minimize consequences if film jam occur	❑	❑	❑	❑	❑	❑	❑	❑	❑
19. Processor able to prevent film mix-up (able to sort film)	❑	❑	❑	❑	❑	❑	❑	❑	❑
20. No leaks of chemicals	❑	❑	❑	❑	❑	❑	❑	❑	❑
21. No external pollution from processor	❑	❑	❑	❑	❑	❑	❑	❑	❑
22. Processor take care of silver	❑	❑	❑	❑	❑	❑	❑	❑	❑
23. Low noise level	❑	❑	❑	❑	❑	❑	❑	❑	❑
24. High processing speed	❑	❑	❑	❑	❑	❑	❑	❑	❑

What is the number of your *most important* requirement:

Why is this your most important requirement:

Comments:

PART II Performance of each requirement compared to your expectations

Please indicate how each requirement meets **YOUR** expectations. Evaluate each requirement based on what you think is the optimal performance that will make you completely satisfied.

	Much Worse	Worse	As Expected	Better	Much Better	N/A
1. Fast and timely first time delivery of processor and components	☐	☐	☐	☐	☐	☐
2. Easy access to the interior of the processor	☐	☐	☐	☐	☐	☐
3. Easy to diagnose and troubleshoot problems	☐	☐	☐	☐	☐	☐
4. Possible to replace parts without removing other components	☐	☐	☐	☐	☐	☐
5. Spare parts always available when needed	☐	☐	☐	☐	☐	☐
6. Fast recovery after problems and stops	☐	☐	☐	☐	☐	☐
7. Long time between failures and stops	☐	☐	☐	☐	☐	☐
8. Easy to replace components	☐	☐	☐	☐	☐	☐
9. The processor operates minimum 8 years before major overhaul	☐	☐	☐	☐	☐	☐
10. Possible to upgrade major components and add new features	☐	☐	☐	☐	☐	☐
11. The processor has a small foot print	☐	☐	☐	☐	☐	☐
12. Easy connection of plumbing	☐	☐	☐	☐	☐	☐
13. Hoses out of the way	☐	☐	☐	☐	☐	☐
14. Fast and easy to fill chemicals	☐	☐	☐	☐	☐	☐
15. Low purchasing costs	☐	☐	☐	☐	☐	☐
16. Low operating costs	☐	☐	☐	☐	☐	☐
17. No film jams in processor	☐	☐	☐	☐	☐	☐
18. Processor able to minimize consequences if film jam occur	☐	☐	☐	☐	☐	☐
19. Processor able to prevent film mix-up (able to sort film)	☐	☐	☐	☐	☐	☐
20. No leaks of chemicals	☐	☐	☐	☐	☐	☐
21. No external pollution from processor	☐	☐	☐	☐	☐	☐
22. Processor take care of silver	☐	☐	☐	☐	☐	☐
23. Low noise level	☐	☐	☐	☐	☐	☐
24. High processing speed	☐	☐	☐	☐	☐	☐

Comments:

Overall performance of the 180LP processor

	Very Poor	Poor	As Expected	Good	Very Good	N/A
How is the reliability of the processor?	☐	☐	☐	☐	☐	☐
How is the user friendliness?	☐	☐	☐	☐	☐	☐
How is the quality of developed film?	☐	☐	☐	☐	☐	☐
How is the serviceability?	☐	☐	☐	☐	☐	☐
How is the responsiveness from the dealer	☐	☐	☐	☐	☐	☐
How is the processing speed?	☐	☐	☐	☐	☐	☐
How is the capacity of the processor?	☐	☐	☐	☐	☐	☐

Comments:

PART III Consequences if your most important requirement fail to meet your expectations

Please list your most important requirement. Try to indicate when the requirement completely meets your expectations and when it becomes unacceptable. For example, for the requirement *"Spare parts always available when required"* 10 minutes may be the optimal performance, you will not achieve anything by having them sooner. The unacceptable limit may be 2 hours; you are not willing to wait that long. Also try to indicate what happens when a requirement fails to meet your expectations. For example, if you don't have the spare part when you need it the consequences might be:

- Waiting time for those who operate the processor.
- Disturbances in your schedule that require rescheduling.
- Waiting time for a patient and his doctor who need the x-ray.
- Rescheduling of the processing to another processor
- Writing of failure reports
- Communication with the service department, the dealer, or Kodak

Please try to list as many consequences as possible.

Requirement: ______________________________

Satisfied when: ______________________________

Dissatisfied when: ______________________________

Consequences:	Downtime (processor)	Time wasted (man-hour)	Direct loss ($)
1. ________	________	________	________
2. ________	________	________	________
3. ________	________	________	________
4. ________	________	________	________
5. ________	________	________	________
6. ________	________	________	________

Comments:

Explanation:

Down time: The time the processor (or other equipment) are out of service because of the poc performance of the requirement.

Time wasted: The time you, your patient, or others waste because the processor is down or tim used to re-schedule other jobs.

Direct loss: This is everything that causes extra costs like waste of film, chemicals, etc. Pleas indicate costs if known or amount wasted.

PART IV Performance of each requirement compared to competing products (IF APPLICABLE)

If you have any experience with other comparable processors from competitors of Kodak, I would like you to indicate *how the 180LP performs compared to these processors*. Please indicate which make and model you have used in your comparison.

Make: ______________________ Model: ______________________

	Much Worse	Worse	As Expected	Better	Much Better	N/A
1. Fast and timely first time delivery of processor and components	☐	☐	☐	☐	☐	☐
2. Easy access to the interior of the processor	☐	☐	☐	☐	☐	☐
3. Easy to diagnose and troubleshoot problems	☐	☐	☐	☐	☐	☐
4. Possible to replace parts without removing other components	☐	☐	☐	☐	☐	☐
5. Spare parts always available when needed	☐	☐	☐	☐	☐	☐
6. Fast recovery after problems and stops	☐	☐	☐	☐	☐	☐
7. Long time between failures and stops	☐	☐	☐	☐	☐	☐
8. Easy to replace components	☐	☐	☐	☐	☐	☐
9. The processor operates minimum 8 years before major overhaul	☐	☐	☐	☐	☐	☐
10. Possible to upgrade major components and add new features	☐	☐	☐	☐	☐	☐
11. The processor has a small foot print	☐	☐	☐	☐	☐	☐
12. Easy connection of plumbing	☐	☐	☐	☐	☐	☐
13. Hoses out of the way	☐	☐	☐	☐	☐	☐
14. Fast and easy to fill chemicals	☐	☐	☐	☐	☐	☐
15. Low purchasing costs	☐	☐	☐	☐	☐	☐
16. Low operating costs	☐	☐	☐	☐	☐	☐
17. No film jams in processor	☐	☐	☐	☐	☐	☐
18. Processor able to minimize consequences if film jam occur	☐	☐	☐	☐	☐	☐
19. Processor able to prevent film mix-up (able to sort film)	☐	☐	☐	☐	☐	☐
20. No leaks of chemicals	☐	☐	☐	☐	☐	☐
21. No external pollution from processor	☐	☐	☐	☐	☐	☐
22. Processor take care of silver	☐	☐	☐	☐	☐	☐
23. Low noise level	☐	☐	☐	☐	☐	☐
24. High processing speed	☐	☐	☐	☐	☐	☐

Comments:

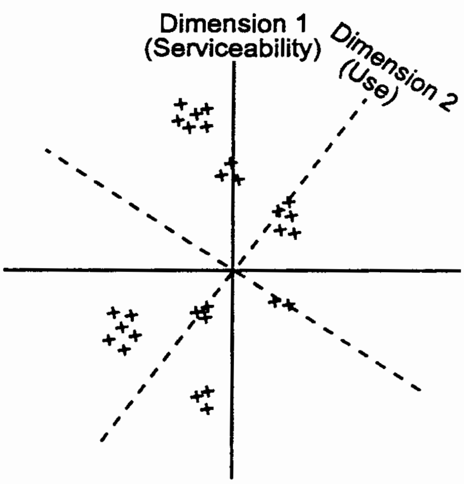
APPENDIX D - CORRESPONDENCE ANALYSIS

Correspondence analysis is a technique used to explore a hidden structure of categorical data through complex mathematical manipulation. Its basic idea has existed for at least half a century, and are known under names like dual scaling, homogeneity analysis, Hayashi's theory of quantification, and more. This appendix is based on "Dual Scaling in a Nutshell" by Shizuhiko Nishisato (1994), who is also the author of the software used in the analysis.

Correspondence analysis is a data reduction technique that quantifies categorical data in a two-way table so as to maximize the between-row and the between-column discrimination simultaneously. In this text, correspondence analysis is used to analyze multiple-choice data. For the case study at Kodak, with 28 responds, 24 items, and 3 options for each item, the data will appear in a 28x72 (24x3=72) incidence or response-pattern matrix.

	Item	**1**			**2**			**....**	**24**			
	Option	**1**	**2**	**3**	**1**	**2**	**3**		**1**	**2**	**3**	**Score**
	1											y_1
Subject	**2**											y_2
	....											....
	28											y_{28}
Weight		x_1	x_2	x_3	x_4	x_5	x_6	....	x_{70}	x_{71}	x_{72}	

Scores y_i and weights x_j are then assigned so as to minimize within-subject discrepancies in the values of weights while maximizing the between-subject differences. This involves rearranging the rows within themselves and the columns within themselves in such a way that the respond lie as close to the diagonal line as possible. This is done within each dimension of the data set.



When the first optimal solution (dimension 1) does not explain the variation in the data exhaustively, correspondence analysis determines a second set of scores and weights that maximally explains another portion of the variation (on dimension 2), unexplained by the first optimal solution. This process is continued until the original data can be perfectly reproduced by the solutions obtained, that is until the variation in the data is exhaustively analyzed. This is called *multidimensional decomposition* of data. What is done operationally is to determine y_i and x_j so as to maximize the correlation ratio η^2 (eta square), where:

$$\eta_x^2 = \frac{\text{Between Subject SS(x)}}{\text{Total SS(x)}} \quad \text{and} \quad \eta_y^2 = \frac{\text{Between Option SS(y)}}{\text{Total SS(y)}}$$

SS(x) and *SS(y)* represent the sums of squares of responses weighted by x_j and responses weighted by y_i. Optimal scores and weights are found when $\eta_x^2 = \eta_y^2 = \rho^2$. The maximized η^2 is equal to the average of the squared correlation between item scores and total scores, where n is the total number of multiple-choice items. r_{jt}^2 is the square of the product-moment correlation between scores of items j and total scores of

$$\eta^2 = \frac{\sum_{j=1}^{n} r_{jt}^2}{n}$$

subjects. r_{jt}^2 is therefore useful in telling which item contribute more to the total score than other items.

$$SS_j = \sum_{i=1}^{N} \sum_{p=1}^{m_j} f_{ijp} x_{jp}^2$$

SS_j is the sum of squares for the weighted responses of item j where f_{ijp} is the response of subject i to option p of item j, and x_{jp} is the weight for option p for item j. SS_j is proportional to r_{jt}^2, so the larger the statistic SS_j, the more important item j is for the entire questionnaire.

Correspondence analysis is used to explore relations between and within heterogeneous questions and subjects, and derives the most reliable score for the subject. The above description applies to the standard correspondence analysis procedure for analyzing multiple-choice data, also referred to as multiple correspondence analysis.

The maximum numbers of solutions (dimensions) that can be extracted is equal to the total number of response options minus the number of items (24x3-24=48 in the Kodak study). This number of solutions is typically too large to analyze. The number of solutions does not influence how much of the total variance that is explained. If too few solutions are used in the analysis, important information may be lost because a solution is not considered. On the other hand, as more solutions are extracted, it becomes increasingly difficult to explain the less-dominant solutions. The number of solutions that should be extracted in the analysis is somewhat arbitrary and usually determined by the analyst of the one interpreting the output.

Since the importance of any solution is determined in large measure by how well, or how clear, the dimension can be defined or explained, it would be impractical to extract all possible solutions. The more solutions that are extracted, the more vague will the accompanying interpretation of that dimension be.

APPENDIX E - CORRESPONDENCE ANALYSIS OF MULTIPLE-CHOICE DATA

Explanation of terms:
Squared Correlation Ratio (η^2) is a statistic ranging from 0 to 1. It indicates the proportion of information one can gain on rows from the knowledge about the data in columns, and vice versa, when "optimal" weights are used.

Product-Moment Correlation (ρ) is equal to the positive square root of η^2, and indicates the amount of linear relationship between responses weighted by row scores y_i and responses weighted by column weights x_j.

Percent Homogeneity is an index of how good the solution is compared with the perfect case where all inter-item correlations are 1 (i.e., one item contains all the information in the data). This statistic is the sum of all possible values of η^2, which is 100 times the correlation ratio.

Delta Partial explains how much of the total variation this dimension accounts for, which is the percentage homogeneity divided by total variation. Reliability Coefficient Alpha indicates to which extent high-score subjects chose options with large weights and low-score subjects chose options with low weights. The optimum value is 1.0. SS_j indicates the relative contribution of item j to the determination of the given dimension. r_{jt}^2 is the square of the product-moment correlation between subject scores for item j and total scores. r_{jt} is the positive square root of r_{jt}^2, and indicates the extent to which item j is correlated with the dimension that has been determined.

Program written by S. Nishisato, 1985
DUAL3MC,VERSION 2.21, NOVEMBER 1987

TOTAL VARIANCE TO BE ACCOUNTED FOR = 1.8586

SOLUTION 1 (Serviceability)
Squared correlation ratio = 0.3600
Product-Moment correlation = 0.6000
Percentage homogeneity = 36.00
Delta (total variance accounted for)
Partial = 19.37, Cumulative = 19.37
Reliability coefficient Alpha = 0.9227

Optimal Scores

1	-0.26	15	-0.48
2	-0.44	16	0.64
3	0.57	17	1.29
4	-0.43	18	1.06
5	-0.61	19	0.70
6	-0.47	20	-0.12
7	0.43	21	-0.38
8	0.23	22	-0.33
9	1.14	23	-0.51
10	0.34	24	-0.32
11	-0.80	25	-0.46
12	0.45	26	-0.69
13	-0.47	27	-0.51
14	-0.24	28	0.63

Item Statistics

Item (j)	SS(j)	r^2(jt)	r(jt)	Item (j)	SS(j)	r^2(jt)	r(jt)
1	7.81	0.1004	0.3169	13	28.14	0.3618	0.6015
2	45.57	0.5859	0.7654	14	63.71	0.8190	0.9050
3	3.06	0.0394	0.1984	15	19.32	0.2484	0.4984
4	61.42	0.7896	0.8886	16	18.00	0.2314	0.4810
5	38.07	0.4894	0.6996	17	9.20	0.1183	0.3439
6	22.83	0.2935	0.5418	18	9.36	0.1203	0.3468
7	12.32	0.1583	0.3979	19	11.84	0.1522	0.3901
8	58.29	0.7493	0.8656	20	29.84	0.3837	0.6194
9	42.29	0.5436	0.7373	21	14.76	0.1897	0.4355
10	47.61	0.6120	0.7823	22	21.27	0.2735	0.5230
11	29.40	0.3780	0.6148	23	12.93	0.1662	0.4076
12	45.37	0.5832	0.7637	24	12.13	0.1559	0.3948

SOLUTION 2 (Use)

Squared correlation ratio = 0.2423
Product-Moment correlation = 0.4923
Percentage homogeneity = 24.23
Delta (total variance accounted for)
Partial = 13.04, Cumulative = 32.40
Reliability coefficient Alpha = 0.8640

Optimal adjusted scores

Optimal Scores

1	-0.08	15	0.09
2	0.24	16	-0.31
3	-0.17	17	0.52
4	-0.04	18	0.34
5	-0.06	19	0.12
6	-0.66	20	0.25
7	-0.24	21	-0.08
8	-0.78	22	-0.16
9	0.24	23	-0.59
10	-0.40	24	1.00
11	0.47	25	-0.52
12	-0.28	26	0.98
13	-0.29	27	-0.59
14	1.17	28	-0.23

Item Statistics

Item (j)	SS(j)	r^2(jt)	r(jt)	Item (j)	SS(j)	r^2(jt)	r(jt)
1	0.27	0.0023	0.0480	13	40.31	0.3488	0.5906
2	7.32	0.0634	0.2517	14	42.98	0.3720	0.6099
3	8.66	0.0749	0.2737	15	15.91	0.1377	0.3710
4	7.23	0.0625	0.2501	16	32.57	0.2819	0.5309
5	3.70	0.0320	0.1788	17	19.42	0.1680	0.4099
6	22.01	0.1905	0.4364	18	43.82	0.3792	0.6158
7	69.00	0.5971	0.7727	19	45.95	0.3976	0.6306
8	3.56	0.0308	0.1756	20	34.35	0.2973	0.5452
9	5.99	0.0518	0.2277	21	49.47	0.4281	0.6543
10	4.96	0.0429	0.2072	22	26.95	0.2332	0.4829
11	37.03	0.3204	0.5661	23	41.59	0.3599	0.5999
12	58.38	0.5052	0.7108	24	42.93	0.3715	0.6095

SOLUTION 3 (Speed of service and available features)

Squared correlation ratio = 0.1801
Product-Moment correlation = 0.4244
Percentage homogeneity = 18.01
Delta (total variance accounted for)
Partial = 9.69, Cumulative = 42.09
Reliability coefficient Alpha = 0.8021

Optimal adjusted scores

Optimal Scores

1	0.92	15	0.00
2	0.77	16	0.69
3	-0.64	17	-0.27
4	0.24	18	-0.46
5	-0.11	19	-0.45
6	-0.02	20	-0.09
7	0.43	21	-0.15
8	0.03	22	-0.69
9	0.36	23	-0.41
10	0.04	24	0.27
11	-0.04	25	-0.28
12	0.38	26	0.39
13	-0.08	27	-0.41
14	-0.71	28	0.21

Item Statistics

Item (j)	SS(j)	r^2(jt)	r(jt)	Item (j)	SS(j)	r^2(jt)	r(jt)
1	7.50	0.0482	0.2196	13	44.23	0.2845	0.5334
2	51.82	0.3333	0.5773	14	23.11	0.1486	0.3855
3	61.61	0.3962	0.6295	15	44.91	0.2889	0.5375
4	46.18	0.2970	0.5450	16	46.00	0.2959	0.5439
5	8.75	0.0562	0.2372	17	2.13	0.0137	0.1170
6	0.07	0.0005	0.0212	18	1.52	0.0098	0.0989
7	9.09	0.0584	0.2418	19	34.96	0.2248	0.4742
8	53.24	0.3424	0.5852	20	4.16	0.0268	0.1636
9	9.47	0.0609	0.2468	21	2.81	0.0181	0.1345
10	51.91	0.3339	0.5778	22	72.69	0.4675	0.6837
11	28.82	0.1853	0.4305	23	24.87	0.1599	0.3999
12	28.37	0.1825	0.4272	24	5.88	0.0378	0.1944

SOLUTION 4 (Cost and use)
Squared correlation ratio = 0.1408
Product-Moment correlation = 0.3752
Percentage homogeneity = 14.08
Delta (total variance accounted for)
Partial = 7.57, Cumulative = 49.67
Reliability coefficient Alpha = 0.7346

Optimal adjusted scores

Optimal Scores

1	0.48	15	0.19
2	0.56	16	-0.06
3	0.66	17	0.19
4	0.22	18	-0.28
5	-0.26	19	0.67
6	0.13	20	0.05
7	0.74	21	-0.48
8	-0.17	22	-0.20
9	-0.82	23	-0.06
10	-0.15	24	-0.46
11	-0.28	25	-0.05
12	-0.32	26	-0.09
13	-0.22	27	-0.06
14	0.37	28	-0.29

Item Statistics

Item (j)	SS(j)	$r^2(jt)$	r(jt)	Item (j)	SS(j)	$r^2(jt)$	r(jt)
1	58.96	0.2964	0.5445	13	5.78	0.0291	0.1705
2	0.90	0.0045	0.0672	14	12.34	0.0620	0.2491
3	8.85	0.0445	0.2109	15	62.75	0.3155	0.5617
4	56.89	0.2860	0.5348	16	69.31	0.3485	0.5903
5	67.32	0.3385	0.5818	17	3.79	0.0191	0.1381
6	27.52	0.1384	0.3720	18	0.03	0.0001	0.0112
7	17.52	0.0881	0.2968	19	23.98	0.1205	0.3472
8	23.19	0.1166	0.3415	20	19.22	0.0966	0.3108
9	11.80	0.0593	0.2435	21	1.91	0.0096	0.0979
10	25.69	0.1292	0.3594	22	59.56	0.2995	0.5472
11	20.49	0.1030	0.3210	23	66.06	0.3321	0.5763
12	8.22	0.0413	0.2033	24	11.57	0.0582	0.2412

SOLUTION 5 (Useful life and use)
Squared correlation ratio = 0.1234
Product-Moment correlation = 0.3513
Percentage homogeneity = 12.34
Delta (total variance accounted for)
Partial = 6.64, Cumulative = 56.31
Reliability coefficient Alpha = 0.6913

Optimal adjusted scores

Optimal Scores

1	0.14	15	-0.41
2	0.09	16	0.27
3	-0.11	17	0.02
4	-0.39	18	-0.11
5	-0.48	19	0.21
6	0.27	20	-0.74
7	-0.30	21	-0.47
8	0.70	22	-0.38
9	-0.01	23	0.18
10	0.11	24	0.55
11	0.37	25	0.20
12	-0.53	26	-0.15
13	0.31	27	0.18
14	0.45	28	0.07

Item Statistics

Item (j)	SS(j)	$r^2(jt)$	r(jt)	Item (j)	SS(j)	$r^2(jt)$	r(jt)
1	37.28	0.1644	0.4054	13	56.59	0.2495	0.4995
2	38.83	0.1712	0.4138	14	20.73	0.0914	0.3023
3	38.72	0.1707	0.4131	15	32.43	0.1430	0.3782
4	3.74	0.0165	0.1284	16	25.71	0.1133	0.3367
5	1.12	0.0049	0.0702	17	1.68	0.0074	0.0862
6	3.80	0.0167	0.1294	18	9.19	0.0405	0.2013
7	50.63	0.2232	0.4725	19	13.18	0.0581	0.2410
8	30.87	0.1361	0.3689	20	17.36	0.0765	0.2766
9	139.78	0.6162	0.7850	21	14.76	0.0651	0.2551
10	68.41	0.3016	0.5492	22	11.92	0.0526	0.2293
11	6.42	0.0283	0.1682	23	20.40	0.0899	0.2999
12	17.97	0.0792	0.2815	24	1.85	0.0081	0.0903

APPENDIX F - PROCESS ANALYSIS TO DETERMINE LOSS

The following pages describe the process analysis and data gathering that were done at Kodak Health Imaging and Strong Memorial Hospital. There is one table for each key process parameter used to calculate critical internal failure costs, and one table for each customer requirement used to calculate external failure costs and customer incurred costs. Data for environmental costs has not been gathered.

Data gathered in each table have been used to construct loss functions in Chapter 6.3. The form is described in more detail in Chapter 6.3.1 on page 80, and Chapter 5.4.1 on page 58.

Notations ^{1,2} and ^{3} indicates resource consumption, and thereby costs, at different tolerances where the performance of the characteristic changes. For instance, the time consumption for troubleshooting in the consequence table on the next page is 2^1 minutes, indicating that it takes 2 minutes to find the problem when the performance exceeds the first tolerance limit. It takes 10 minutes (10^2) to find the problem if the performance exceeds the second tolerance limit.

Internal Failure Costs for No Film Jams in Processor

Customer requirement: No film jams in processor

Cost category: ☑ Internal Failure ☐ External Failure ☐ Customer Incurred ☐ Environmental

Key process parameters: ❶ Position of film guides

Type of characteristic: ☐ Smaller-the-better ☑ Target-the-best ☐ Larger-the-better

Performance:
- Satisfactory: <± 0.005"
- Shift: <± 0.010", problem resolved in rack area
- Unsatisfactory: >± 0.010", problem discovered at setup and test station, product returned to rack area for repair

Failure/non-conformance:
- Wrong position of assembly hole
- Wrong curvature of guide shoe
- Stiffener positioned wrongly

Cost driver: Number of failures

CONSEQUENCES:

ACTIVITIES	COST ELEMENTS: Labor, Direct		Labor, Indirect		Material, Direct		Material, Indirect		Process, Direct		Process, Indirect		Facility, Direct		Facility, Indirect		Total for Cost Driver
	Who	Time	Who	Time	What	Volume	What	Volume	Which	Time	Which	Time	Which	Area	Which	Area	
Trouble shooting	Op Op Eng	2[1] 10[2] 2[2]			Film	1[2]											$1.90[1] $15.80[2]
Rework	Op Op	3[1] 30[2]			Shoe	1[1,2]											$13.90[1] $40.00[2]
Delay			Op (S&T)	30[2]													$29.00[2] 0[1,2]
Re-planning																	$2.90[2]
Return to rack area	Op	3[2]															$9.70[2]
Re-testing	Op	10[2]															$8.00[2]
Reporting	Op Eng	3[2] 2[2]	Adm	1[2]													
Cost at ± 0.005[1] Cost at ± 0.01[2]		$4.80[1] $62.20[2]		$30.00[2]		$11.00[1] $13.00[2]											$15.80[1] $105.30[2]

Labor Costs:
- Operator: $58 per hour
- Engineer: $123 per hour
- Admin: $58 per hour

Material Costs:
- Shoe: Restricted Information
- Film: Restricted Information

Process Costs: Mainly labor costs

Labor costs are based on full burden which includes costs of facilities. Actual costs for these elements were not available. S&T equals setup and testing.

Customer requirement: No film jams in processor

Cost category: ☑ Internal Failure ☐ External Failure ☐ Customer Incurred ☐ Environmental

Key process parameters: ❷ Position of rollers

Type of characteristic: ☐ Smaller-the-better ☑ Target-the-best ☐ Larger-the-better

Performance:
- Satisfactory: <± 0.002"
- Shift: <± 0.005", problem resolved in rack area
- Unsatisfactory: >± 0.005", problem discovered at setup and test station, product returned to rack area for repair

Failure/non-conformance:
- Rollers are unseated
- Gears are not meshing
- Shaft or bearing out of position

Cost driver: Number of failures

CONSEQUENCES:

ACTIVITIES	COST ELEMENTS: Labor – Direct Who	Labor – Direct Time	Labor – Indirect Who	Labor – Indirect Time	Material – Direct What	Material – Direct Volume	Material – Indirect What	Material – Indirect Volume	Process – Direct Which	Process – Direct Time	Process – Indirect Which	Process – Indirect Time	Facility – Direct Which	Facility – Direct Area	Facility – Indirect Which	Facility – Indirect Area	Total for Cost Driver
Trouble shooting	Op Op Eng	7[1] 45[2] 5[2]			Film	1[2]											$6.80[1] $55.75[2]
Rework	Op Op	8[1] 45[2]			Roller	1[1,2]											$20.95[1] $56.70[2]
Delay			Op (S&T)	45[2]													$43.50[2]
Re-planning																	0[1,2]
Return to rack area	Op	3[2]															$2.90[2]
Re-testing	Op	10[2]															$9.70[2]
Reporting	Op Eng	3[2] 2[2]	Adm	1[2]													$8.00[2]
Cost at ± 0.002[1] Cost at ± 0.005[2]		$14.50[1] $116.80[2]		$44.50[2]		$13.25[1] $15.25[2]											$27.75[1] $176.55[2]

Labor Costs:
- Operator: $58.00 per hour
- Engineer: $123.00 per hour
- Admin: $58.00 per hour

Material Costs:
- Roller: Restricted Information
- Film: Restricted Information

Process Costs: Mainly labor costs

Labor costs are based on full burden which includes costs of facilities. Actual costs for these elements were not available. S&T equals setup and testing.

Customer requirement: No film jams in processor

Cost category: ☑ Internal Failure ☐ External Failure ☐ Customer Incurred ☐ Environmental

Key process parameters: ❸ Position of entrance switch

Type of characteristic: ☐ Smaller-the-better ☑ Target-the-best ☐ Larger-the-better

Performance:
- Satisfactory: < +0.03/ -0.04"
- Shift: < +0.05/ -0.1", problem resolved in rack area
- Unsatisfactory: > +0.05/ -0.1", problem discovered at setup and test station, product returned to rack area for repair

Failure/non-conformance: Switch is out of position

Cost driver: Number of failures

CONSEQUENCES:

ACTIVITIES	COST ELEMENTS: Labor, Direct		Labor, Indirect		Material, Direct		Material, Indirect		Process, Direct		Process, Indirect		Facility, Direct		Facility, Indirect		Total for Cost Driver
	Who	Time	Who	Time	What	Volume	What	Volume	Which	Time	Which	Time	Which	Area	Which	Area	
Trouble shooting	Op Eng	$5^{1,2}$ 2^{2}			Film	1^{2}											$4.80^{1} $10.90^{2}
Rework	Op Op	5^{1} 15^{2}			Switch	$1^{1,2}$											$9.80^{1} $19.50^{2}
Delay			Op (S&T)	15^{2}													$14.50^{2}
Re-planning																	$0^{1,2}$
Return to rack area	Op	3^{2}															$2.90^{2}
Re-testing	Op	10^{2}															$9.70^{2}
Reporting	Op Eng	3^{2} 2^{2}	Adm	1^{2}													$8.00^{2}
Cost at ± 0.04^{1} Cost at ± 0.1^{2}		$9.60^{1} $43.00^{2}		$15.50^{2}		$5.00^{1} $7.00^{2}											$14.60^{1} $65.50^{2}

Labor Costs:
- Operator: $58.00 per hour
- Engineer: $123.00 per hour
- Admin: $58.00 per hour

Material Costs:
- Switch: Restricted Information
- Film: Restricted Information

Process Costs: Mainly labor costs

Labor costs are based on full burden which includes costs of facilities. Actual costs for these elements were not available. S&T equals setup and testing.

External Failure Costs for No Film Jams in Processor

Customer requirement: No film jams in processor

Cost category: ☐ Internal Failure ☑ External Failure ☐ Customer Incurred ☐ Environmental

Key process parameters: N/A

Type of characteristic: ☑ Smaller-the-better ☐ Target-the-best ☐ Larger-the-better

Performance: Satisfactory: =< 1 per month
Shift: > 1 per month, complaint and adjustment done by customer
Shift: > 4 per month, replacement of components done by dealer or Kodak
Unsatisfactory: > 10 per month, replacement of processor

Failure/non-conformance: Processor out of service

Cost driver: Number of complaints

CONSEQUENCES:

ACTIVITIES	COST ELEMENTS: Labor				Material				Process				Facility				Total for Cost Driver
	Direct		Indirect		Direct		Indirect		Direct		Indirect		Direct		Indirect		
	Who	Time	Who	Time	What	Volume	What	Volume	Which	Time	Which	Time	Which	Area	Which	Area	
Complaint handling	Eng	55[1,2,3]															$113[1,2,3]
Verifying failure	Tech	300[3]	Eng	300[3]													$905[3]
Field repair	Tech	240[2]							Travel	$350[2]							$582[2]
Warranty expenses	Tech	240[3]			Part* Proc.	1[2] 1[3]			Ship Ship	$15[2] $500[3]	Travel	$350[3]					$33[2] $21,082[3]
Analysis of returns	Tech Tech	5[2] 300[3]	Eng	300[3]													$5[2] $905[3]
Handling of returns									Parts Proc.	$96[2] $5000[3]							$96[2] $5,000[3]
Cost of complaint[1] Cost of parts return[2] Cost of processor return[3]		$113[1] $350[2] $925[3]		$1230[3]		$18[2] $20000[3]				$461[2] $5500[3]		$350[3]					$113[1] $829[2] $28,005[3]

Labor Costs:
- Operator: $58.00 per hour
- Engineer: $123.00 per hour
- Admin: $58.00 per hour
- Technician: $58.00 per hour

Material Costs (external cost):
- 180LP: $20,000.00
- Shoe: Restricted Info.
- Roller: Restricted Info.
- Switch: Restricted Info.

Weighted average cost of parts: $18.00*

Process:
- Handling of returned parts: $96.00
- Handling of returned processor: $5,000.00
- Field trip and night stop: $350.00
- Shipment of new parts: $15.00
- Shipment of new processor: $500.00

Labor costs are based on full burden which includes costs of facilities. Actual costs for these elements were not available.

Customer Incurred Costs for No Film Jams in Processor

Customer requirement: No film jams in processor

Cost category: ☐ Internal Failure ☐ External Failure ☑ Customer Incurred ☐ Environmental

Key process parameters: N/A

Type of characteristic: ☑ Smaller-the-better ☐ Target-the-best ☐ Larger-the-better

Performance:
- Satisfied: <1 per month, each 30 min
- Shift: <4 per month, each 30 min (requires more thorough investigation from Service Technician to find failure cause)
- Dissatisfied: >10 per month, each 30 min (have to replace the processor)

Failure/non-conformance: Processor out of service

Cost driver: Number of film jams

CONSEQUENCES:

ACTIVITIES	COST ELEMENTS: Labor, Direct, Who	Labor, Direct, Time	Labor, Indirect, Who	Labor, Indirect, Time	Material, Direct, What	Material, Direct, Volume	Material, Indirect, What	Material, Indirect, Volume	Process, Direct, Which	Process, Direct, Time	Process, Indirect, Which	Process, Indirect, Time	Facility, Direct, Which	Facility, Direct, Area	Facility, Indirect, Which	Facility, Indirect, Area	Total for Cost Driver
1. Notify service	XT ST	5 10	Ra Patient	10 10					180LP	10	Printer	10					$32.8
2. Trouble shooting	ST	30	Ra Patient	5 5	Tools	-			180LP	30	Printer	30					$39.9
3. Repair/recovering	ST	90			Film Chem	3 -			180LP	90	Printer	90					$103.5
4. Re-routing of print	XT	15							Netw.	-							$6.3
5. Re-printing	XT	15			Film Chem	- -			Alt. Proc.	-							$6.3
6. Reporting	XT ST	5 10			PC	-											$6.3
7. Decreased patient care			Nurse	10									Bed	15			$14.6
Total for Cost Driver		$75		$35		$15				$34		$40		$10			$209 per jam

Labor Cost:
- X-ray Tech: $25.00 per hour
- Service Tech: $25.00 per hour
- Nurse: $25.00 per hour
- Radiologist: $75.00 per hour
- Patient: $50.00 per hour

Material Cost:
- Film: $5.00 each
- Chemicals: Included in film cost

Process Cost:
- 180LP: $15.70 per hour
- Printer: $18.30 per hour

Facility:
- Patient bed: $41.70 per hour

APPENDIX G - CALCULATION OF LOSS INTEGRAL

This is a Microsoft Excel function that calculates the estimated loss for one interval of the loss function, where X has a normal (μ, σ^2) distribution. The command NormSDist(z) returns the area from ÷infinity to z for the N(0, 1) distribution. The prefix "Application" means that this is an Excel function, not a Visual Basic function. The integral consists of one constant part, one linear part, and a quadratic part.

```
Function Loss(b, k, T, L1, L2, mu, sigma)
        L1p = (L1-mu) / sigma
        L2p = (L2-mu)/sigma
        Lossconst=k*((T-mu)*(T-mu) -b)*(Application.NormSDist(L2p) - Application.NormSDist(L1p))
        Losslin = k*(T - mu) * sigma * 0.79788 * (Exp(-L2p * L2p / 2) - Exp(-L1p * L1p / 2))
        LossL2quad = -L2p * Exp(-L2p * L2p / 2) + 2.50663 * Application.NormSDist(L2p)
        LossL1quad = -L1p * Exp(-L1p * L1p / 2) + 2.50663 * Application.NormSDist(L1p)
        Lossquad = k * sigma * sigma * 0.39894 * (LossL2quad - LossL1quad)
        Loss = Lossconst + Losslin + Lossquad
End Function
```

$$0.79788 = \frac{\sqrt{2}}{\sqrt{\pi}}, \qquad 2.50663 = \sqrt{2\pi}, \qquad 0.39894 = \frac{1}{\sqrt{2\pi}}$$

m:	0	St	0.5
n:	3	x-mean:	1.0
L1	0		
L2	1	c1	0
L3	4	c2	209
L4	10	c3	1,190
L5		c4	12,090
L6		c5	
L7		c6	
T:	0	c7	

Performance values are entered into the matrix to the left, where *m* is the number of intervals on the left side of the target value and *n* is the total number of intervals in the loss function. *L1* - *L7* is values of *X* where the performance of the characteristic changes, and *c1* - *c7* are corresponding costs. This specific matrix is from the calculation of customer incurred costs in the case study (Chapter 6.3.4 on page 88), and represent a smaller-the-better characteristic. The same approach applies for target-the-best characteristics and larger-the-better characteristics. The only difference is that for a smaller-the-better characteristic $m=0$, and for a larger-the-better characteristic $n=0$. The result appears as in the matrix below, where the values of *a*, *b*, and *k*, and the loss, are automatically calculated based on the entered information. The loss is given for each interval of the loss function.

a-value	b-value	k-value	Target	L_1	L_2	x-mean	Std	Estimated Loss
3.196	0.000	209.000	0.00	0.00	1.00	1.00	0.50	66.94
3.196	-2.196	65.400	0.00	1.00	4.00	1.00	0.50	138.76
0.573	6.829	129.762	0.00	4.00	10.00	1.00	0.50	0.00
								Total 185.71

APPENDIX H - DEFINITIONS AND EXPLANATIONS

Competitive Benchmarking is the process of examining a competitor's product or service according to specific standards, and compare it to one's own product or service, with the objective of deciding how to improve one's own product or service.

Consequence costs are all additional costs related to direct failure costs like administration, disturbances in current and related processes, additional planning, etc. These costs are monitored with the use of Activity Based Costing (ABC).

Critical failures. Failures that have a direct influence on the performance of key characteristics and thereby the fulfillment of customer requirements.

Customer dissatisfaction costs are costs that occur when a customer refrain from re-purchasing a product because he or she is dissatisfied with the product's overall performance.

Customer incurred costs embrace all direct financial consequences experienced by the customer as a result of unsatisfactory quality supplied the producer.

Direct failure costs consist of two elements. *Internal failure costs* that embrace all direct financial consequences of every error, defect, mistake, fault and failure that are discovered before shipment to the customer. *External failure costs* include all direct costs associated with claims, customer rejects, warranty administration and lawsuits as a result of problems that are discovered after shipment.

Environmental costs. This element has not been further emphasized or described.

Functional or process benchmarking is an evolution of competitive benchmarking where the focus has shifted from products to specific functions or processes in the company. Benchmarking partners are not only competitors but also non-competing companies.

Key characteristic. A feature whose variation has the greatest impact on the fit, form, performance or service life of the finished part, product, or service from the perspective of the customer.

Key process parameter. Measurable and controllable process parameters that contribute to variation in key characteristics.

Lack of process efficiency costs are the financial result of non-optimal processes, that is insufficient process performance compared to chief competitor, or theoretical optimal process performance.

Loss-of-reputation costs occur when the customer refrain from buying any products from the manufacturer because he or she has poor experience with one specific product. This cost element reflects the customer's attitude towards the company rather towards a specific product.

Measurement. The act or process of measuring to compare results to requirements. This is a quantitative measure of performance.

Non-critical failures. Failures that have no influence on the performance of key characteristics that affect the core product or service as identified by the customer. These failures do represent improvement potentials internally, despite their lack of influence on key characteristics.

Process. Interrelated resources and activities that is characterized by a specific input, and a value-adding task that produces a specific output.

Process parameter. Controllable factor in a process assumed to influence its result.

Process step. Single activities within each sub-process.

Product. Results of activities or processes, including physical products, services in conjunction with the physical product, or independent services.

Quality (in a wider sense). The avoidance of financial loss to the society, where the loss to society is considered to be the long term loss to the company as a result of poor quality. Quality is measured by Taguchi's loss function where loss accumulates as a result of a key characteristic's deviation from a target value.

Quality (in production). Conformance to specifications (requirements) measured by failure rates.

Sub-process. Parts of a process that consist of consecutive activities that have natural limits to other sub-processes.

Work unit. A group of interdependent process steps that form one or more sub-process.

World class manufacturing. Manufacturing done by a company that is best within their industry on enough competitive edges so as to be able to achieve impressive profits and still beat the competition in the marketplace.

Some of these definitions are based on ISO 8402 (1994) and Boeing's Advanced Quality System for Boeing Suppliers. General definitions to the field of quality can be found in ISO 8402 (1994).

APPENDIX I - RESULTS FROM CUSTOMER SURVEY

This is a summary of the results from the customer survey that was accomplished at Strong Memorial Hospital and S&W X-ray. A description of each customer requirement can be found in the questionnaire (Appendix C). Empty entries indicates no respond. Gray columns represent requirements that was not applicable for the specific group, that was omitted after the survey had been completed.

Demographic information and importance of each requirement (Appendix C, part I)

						Customer Requirements																								
	Job Function	WP	Inv	Yx	Md	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	MI
	Service tech	1	1	15	60	8	8	7	8	9	7	6	8	7	7	5	6	6	6	3	3	7	6	3	6	5	3	3	5	5
	Service tech	1	3	14	6	4	8	8	8	8	8	8	7	6	6	5	7	7	6	5	7	7	8	5	8	6	3	8	8	3
	Service tech	2	3	11	8	9	9	8	7	9	9	9	6	5	1	1	1	9	5	5	5	9	9	1	9	9	1	5	5	5
	Service tech	2	2	8	1	2	9	7	7	8	8	7	8	1	8	3	8	8	6	4	4	8	8	5	9	9	8	8	6	2
	Service tech	2	2	4	48	2	9	9	9	9	9	7	9	4	8	9	9	9	9	1	1	9	8	9	9	7	8	5	6	17
User	Service tech	2	1	12	12	8	8	8	8	8	8	8	8	8	8	8	8	8	8	9	9	9	9	9	9	9	9	8	7	5
Gr. 1	Service tech	2	1	3	30	8	6	6	7	9	6	6	7	7	8	6	6	6	6	6	6	9	9	6	6	6	6	6	6	5
	Service tech	2	2	1	9	9	8	9	7	9	7	9	7	9	8	9	9	8	8	8	8	9	9	8	8	8	6	7	8	7
	Sales	2	4	4	1	9	7	7	7	9	7	6	6	6	6	5	5	5	6	7	4	5	5	6	9	8	5	5	6	1
	QA tech	1	2	9	4	7	7	7	7	7	7	7	7	5	5	5	7	7	7	5	6	8		5	7	7	7	5	7	17
	Average Importance					6.6	7.9	7.6	7.5	8.5	7.6	7.3	7.3	5.8	6.5	5.6	6.6	7.3	6.7	5.3	5.3	8.0	7.9	5.7	8.0	7.4	5.6	6.0	6.4	5
	Priority=Importance/Perf.					2.0	2.3	2.0	2.1	2.3	2.1	2.2	2.1	1.9	1.9	1.6	2.0	2.1	2.0	1.8	1.7	2.7	2.4	1.7	2.6	2.3	2.0	1.9	1.8	17
	X-ray tech	1	1	4	60	7	1	1	1	7	9	9	1		1	9		7	1	1	1	9	7	1	7	7	1	7	7	17
	X-ray tech	1	5	23	0	9	7	7	5	7	7	9	7	4	4	7	2	6	5	4	4	9	9	5	7	7	7	7	7	17
	X-ray tech	1	1	5	510	5	9	6	5	9	9	9	9	7	7		9	8	8	9	9	7	9	9	9	9	8	8	9	0
User	X-ray tech	1	1	11	240	6	7	6	6	6	8	8	6	3	4	2	2	2	3	2	2	8	8	7	9	7	2	8	9	20
Gr. 2	X-ray tech	1	1	12	30	1	1	8	1	1	5	5	1	1	1	8	1	8	1	1	1	9	9	8	5	5	1	5	8	17
	X-ray tech	1	2	4	6	7	1	9	1	5	9	9	3	7	1	8	1	5	1	1	1	9	9	8	9	5	1	1	9	17
	Average Importance					5.8	4.3	6.2	3.2	5.8	7.8	8.2	4.5	4.4	3.0	6.8	3.0	6.0	3.2	3.0	3.0	8.5	8.5	6.3	7.7	6.7	3.3	6.0	8.2	17
	Priority=Importance/Perf.					1.9	1.7	2.5	0.0	2.9	2.4	2.3	0.0	4.4	1.0	1.7	0.0	2.1	1.1	1.0	3.0	2.7	3.0	2.1	3.3	2.1	0.0	2.0	2.4	9
	Radiologist	1	4	20	0	6	6	6	5	7	9	9	6	7	5	4	3	2	5	8	7	9	7	4	8	7	6	7	7	7
	Radiologist	1	1	40	36	6	3	9	3	7	9	9	3	7	7	3	3	3	3	5	7	9	9	9	7	7	7	5	7	6
	Radiologist	1	1	3	50	9	9	9	1	1	9	9	1	1	1	1	1	1	1	9	9	9	9	9	4	9	5	5	9	24
	Administration	1	5	37	0	9	1	1	1	1	9	1	9	9	9	1	1	1	9	9	9	9	9	9	9	9	9	9	9	16
	Administration	1	2	31	0	6	6	9	9	8	9	7	9	8	7	6	7	6	7	5	5	6	5	5	8	6	8	8	6	9
User	Tech superv.	1	2	18	120	1	3	4	1	1	4	6	1	1	1	1	1	1	1	4	4	9	9	9	3	5	5	6	9	24
Gr. 3	Tech superv.	1	1	25	120	9	5	5	5	9	9	9	5	5	5	8	5	5	5	7	7	9	7	5	8	5	5	8	8	0
	Tech superv.	1	1	15	60	1	3	7	3	3	8	8	5	3	5	2	3	7	1	5	5	9	7	8	7	9	5	8	9	24
	Tech superv.	1	0	22	0	8	7	6	7	8	7		8	7	8			5	7	6	6	9	8	8	9	9	8	7	8	3
	Tech superv.	1	5	26	0	7	5	4	2	4	7	2	3	3	3	1	1	2	2	5	5	8	8	9	7	8	6	7	8	19
	Tech superv.	1	1	20	30	5	3	7	3	7	6	6	3	1	1	1	1	1	1	1	1	8	7	6	2	1	1	1	9	24
	Average Importance					6.1	4.6	6.1	3.6	5.1	7.8	6.6	4.8	4.7	4.7	2.8	2.6	3.1	3.8	5.8	5.9	8.5	7.7	7.4	6.5	6.8	5.9	6.5	8.1	17
	Priority=Importance/Perf.					1.5	1.4	1.9	1.1	1.3	2.2	1.7	1.3	1.6	1.4	0.8	0.7	0.8	1.3	1.7	1.5	2.4	2.2	2.1	1.8	1.6	2.5	1.6	2.0	19
	Marketing	3	1	6	15	9	7	9	7	9	8	8	8	7	7	8	7	7	7	8	8	8	8	7	9	9	8	7	8	3
	Overall Importance					5.7	3.2	3.7	3.0	3.4	7.7	7.0	2.9	4.7	5.3	0.7	2.6	0.6	2.7	2.9	3.0	8.3	7.9	4.3	7.2	4.1	2.2	3.8	4.9	17
	Weighted Priority					1.6	0.9	1.1	0.8	0.9	2.2	2.0	0.8	1.6	1.5	0.2	0.8	0.2	0.8	0.9	0.7	2.5	2.4	1.3	2.3	1.0	0.8	1.0	1.3	17

User groups: Groups identified through correspondence analysis (Appendix D, Appendix E)

WP: Work Place where: 1 = Strong Memorial Hospital
2 = S&W X-ray
3 = Kodak (not included in the analysis)

Inv: How often the respondents are involved with the processor, where
1 = Daily, 2 = Weekly, 3 = Monthly, 4 = Annually, 5 = Never

Yx: How many years of experience each respondent has in a X-ray department or with X-ray processors.

Md: Minutes per day used in connection with the 180LP processor.

MI: Most important requirement.

Priority: Average importance divided by performance (represented on the next page).

Performance of each requirement and overall performance

		Customer Requirements																								Overall Performance						
	Job Function	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5	6	7
User Gr. 1	Service tech	3	3	3	4	4	3	3	3		3	3	3	3	4	3	3	3	3		2	3		3	3	4	4	4	4	4	4	4
	Service tech	3	5	5	5	4	5		5		3	4	4	5	4	3	4	5	4		4	4		4	5	5	5	5	5	4	5	5
	Service tech	4	3	5	4	5	3	4	4	3	3	4	3	3	3			3	4	4	3	4		3	4	4	4	5	4	5	4	4
	Service tech	3	2	3	3	4	3	3	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	5	3	5	4	4
	Service tech		5	5	4	3	5	3	5	3	5	4	5	5	5			5	5	5	5	3	3	3	4	5	4	5	5	5	4	4
	Service tech	3	5	4	4	5	4	4	4	4	4	4	3	3	3	3	3	2	3	3	3	3	3	3	3	4	4	5	4	4	5	5
	Service tech	3	2	3	2	3	3	3	2	3	4	3	3	3	3	3	3	1	1	3	2	3	3	3	3	3	3	3	2	3	3	3
	Service tech	3	3	3	3	3	3	2	3		3	3	3	3	2	3	3	2	3	3	3	3	2	3	3	3	3	4	3	3	3	4
	Sales	4										3				2					3			3		3	4	4	4	5	4	4
	QA tech	3	3	3	3	3	3	5		3	3	3	3	3		3	3	3	3	3	3	3	3	3	3	4	4	4	4	5	5	5
	Avg. Gr. Perf.	3.2	3.4	3.8	3.6	3.8	3.6	3.4	3.5	3.0	3.4	3.4	3.3	3.4	3.4	2.9	3.1	3.0	3.2	3.4	3.1	3.2	2.8	3.1	3.6	3.9	3.9	4.4	3.8	4.3	4.1	4.2
User Gr. 2	X-ray tech						5	5				5		3				5	3			5		5	5	5	5	5			5	5
	X-ray tech																															
	X-ray tech		2	2			2	3		1	3			3		3	1	2	2	3	2	2		3	3	2	3	4	1	2	3	3
	X-ray tech		3	2		2	3	3						2	3			2	3		2	3		1	3	4	3	5	4	5	3	3
	X-ray tech	3		3			3				3	3		2				3	3	3	3	3		3	3	5	4	4			5	4
	X-ray tech			3			3	3				4		4				4	3	3				3	3	3	3	3			3	3
	Avg. Gr. Perf.	3.0	2.5	2.5	0.0	2.0	3.2	3.5	0.0	1.0	3.0	4.0	0.0	2.8	3.0	3.0	1.0	3.2	2.8	3.0	2.3	3.3	0.0	3.0	3.4	3.8	3.6	4.2	2.5	3.5	3.8	3.6
User Gr. 3	Radiologist	3					3	3				3				2	3	2			2	3	1	3	3	3	3	4			3	3
	Radiologist						4	4			4							4	4	5	4			5	5	5		5		5	5	5
	Radiologist	3	3	3	3	3		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	5	3	3	5	5
	Administration																															
	Administration																															
	Tech superv.		3	2			2											2	2	3				3	3	2	3	5	2		4	4
	Tech superv.	5	3	3	3	5	5	5	3	3	3	4	3	3	3	5	5	5	5	3	4	5	3	4	4	5	4	4	4	5	4	4
	Tech superv.	4									4		5	5				5				5		5	5	5	4	5	4		5	5
	Tech superv.	5	4	5	4	4	5	5	5								5	5	4		5	5		5	5							
	Tech superv.																															
	Tech superv.			3			3	3										3	3						4	4	3	4	4			3
	Avg. Gr. Perf.	4.0	3.3	3.2	3.3	4.0	3.6	3.8	3.7	3.0	3.5	3.3	3.7	3.7	3.0	3.3	4.0	3.6	3.5	3.5	3.6	4.2	2.3	4.0	4.0	4.0	3.5	4.6	3.4	4.3	4.3	4.1
	Marketing	5	3	4	3	4	5	5	4	3	4	5	4	3	3	5	5	5	5	4	5	5	4	3	4	2	3	3	6	3	3	3
	Overall Perf.	3.5	3.3	3.3	3.5	3.7	3.5	3.6	3.5	2.8	3.4	3.5	3.4	3.3	3.3	3.0	3.3	3.3	3.2	3.4	3.1	3.5	2.7	3.4	3.7	3.9	3.7	4.4	3.5	4.2	4.1	4.0

This is a continuation of the previous table where the respondent were asked to indicate how each requirement meet their expectations. The overall performance of the 180LP processor was also evaluated.

Competitive analysis

A — **Performance of Kodak 180LP**
Customer Requirements

Job Function	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Service tech	3	3	3	4	4	3	3	3		3	3	3	3	4	3	3	3	3		2	3		3	3
Service tech	4	3	5	4	5	3	4	4	3	3	4	3	3	3			3	4	4	3	4		3	4
Service tech	3	2	3	3	4	3	3	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4
Service tech		5	5	4	3	5	3	5	3	5	4	5	5	5			5	5	5	5	3	3	3	4
Service tech	3	5	4	4	5	4	4	4	4	4	4	3	3	3	3	3	2	3	3	3	3	3	3	3
Average	3.3	3.6	4.0	3.8	4.2	3.6	3.4	3.6	3.0	3.6	3.6	3.4	3.4	3.6	3.0	3.0	3.2	3.6	3.8	3.2	3.2	3.0	3.0	3.6

B
Continue — **Performance of Competing Products (Fuji)**
Customer Requirements

Model	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Fuji FYIX	2	3	3	2	1	3	3	2		3	4	3	3	2			3	3	3	3	3	3	3	3
Fuji 422	2	1	1	1	1	1	3	1		2	3	2	3	3			3	2	1	3	3		3	2
Fuji 3543	2	1	1	1	1	1	3	1	3	2	3	3	3	2	3	3	3	3	3	3	3	3	3	2
Fuji 422	3	2	2	1	2	3	3	2	3	3	3	3	3	3			3	2			3	3	4	3
Fuji 422	3	1	2	1	1	3	3	1	2	2	3	3	2	3	3	3	3	3	3	3	3	3	3	3
Average	2.4	1.6	1.8	1.2	1.2	2.2	3.0	1.4	2.7	2.4	3.2	2.8	2.8	2.6	3.0	3.0	3.2	2.6	2.5	3.0	3.0	3.0	3.2	2.6

Performance Index used in the QFD Matrix (Average Competitive Rating - Average Kodak Performance)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
B - A	-1	0	0	-2	-3	0	0	-1	0	0	1	0	0	-2	0	0	0	0	0	1	0	0	0	0
B - A	-2	-2	-4	-3	-4	-2	-1	-3	0	-1	-1	-1	0	0	0	0	0	-2	-3	0	-1	0	0	-2
B - A	-1	-1	-2	-2	-3	-2	0	-1	1	-1	0	0	0	-1	0	0	0	0	0	0	0	0	0	-2
B - A	3	-3	-3	-3	-1	-2	0	-3	0	-2	-1	-2	-2	-2	0	0	-2	-3	0	0	0	0	1	-1
B - A	0	-4	-2	-3	-4	-1	-1	-3	-2	-2	-1	0	-1	0	0	0	1	0	0	0	0	0	0	0
Av. B - Av. A	-0.9	-2.0	-2.2	-2.6	-3.0	-1.4	-0.4	-2.2	-0.3	-1.2	-0.4	-0.6	-0.6	-1.0	0.0	0.0	-0.2	-1.0	-1.3	-0.2	-0.2	0.0	0.2	-1.0

The results are from five respondents who compared the performance of the 180LP processor with the performance of competing Fuji products. They were all service technicians from S&W X-ray. The different Fuji models were regarded quite similar, and analyzed as one to obtain more data.

Table A shows individual and average rating of performance for the 180LP, while table B shows their evaluation of Fuji's performance. The last table shows the performance index which is the performance of the 180LP minus the performance of Fuji products. A negative performance index indicates that the 180LP performs better than the competing product.

The performance index is used in the QFD matrix to estimate intangible costs in Chapter 6.4 on page 90.