

An analysis of field feedback in consumer electronics industry

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AN ANALYSIS OF FIELD FEEDBACK IN CONSUMER
ELECTRONICS INDUSTRY

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de
Technische Universiteit Eindhoven, op gezag van de
Rector Magnificus, prof.dr. R.A. van Santen, voor een commissie
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Summary

During the last decades the combination of technological innovation and pressure on time to market urges manufacturers to shorten their product creation processes. In order to make a profit, manufacturers have to be first on the market with products that have state-of-the-art functionality, relatively high quality, and competitive prices.

In their efforts to be first on the market, manufacturers tend to choose seemingly obvious solutions like skipping time consuming activities such as testing. However, if such drastic decisions are taken without a thorough analysis of the consequences, possible risks are overlooked and immature products are put on the market. These risks are even more relevant for strongly innovative products, since, due to a combination of extra market uncertainty and technical complexity, the likelihood that something is missed is in this situation much larger.

A challenge for manufacturers rises: how to predict, evaluate and improve the quality and reliability of products in the hands of the customer. This requires among other things that the manufacturers collect data about the real performance of the products, in other words: field feedback information.

The collection and analysis of informative field feedback about product reliability is the main topic of this thesis. The first part of the thesis reflects the state-of-the-art as presented in the relevant literature; next, two cases are studied in detail; and finally improvement activities are proposed and tested in a real situation concerning a new and innovative product.

The literature research identified the following gaps:

- The component related product failure information describes only a small part of the current failure mechanisms in consumer electronics.
- The speed of the current field feedback information flow does not seem high enough for timely product quality improvements.
- According to the available literature, the field information needed for the determination of the field behaviour of a product is available. However, given the lack of papers in which the available field information is analysed and used for product quality improvement, the literature might be too optimistic.
- Information is only useful when it is in time; therefore the speed of the field feedback loop in relation to the PCP has to be investigated.
- The currently available prediction and analysis techniques are mostly based on the constant failure rate assumption, although this assumption is usually not valid.

Next, two cases are presented that demonstrate what is wrong with the present way of collecting and analysing field information: the field feedback information is not in time and not well analysed. The case studies are performed at two multinational manufacturers of consumer electronics. In these cases field feedback information is subdivided in engineering (technical) information, and statistical information. Engineering information concerns the information that is required in order to be able

to detect the root cause of a problem. This implies that engineering information is vital for product improvement. Statistical information concerns the frequency of product failures; this type of information is hardly useful for product improvement, but it gives information about (sub-) populations of products and it facilitates statements about the overall product quality, for example in terms of the fraction of products that fail within the warranty period.

Finally, the above-mentioned gaps are analysed concentrating on engineering field failure information and on statistical field failure information. The results are compared with the findings of the literature study. This leads to the following conclusions:

- Although the two companies have different characteristics, the field feedback systems they use are quite similar.
- The available field feedback is incomplete and not suitable for root cause analyses.
- There is no direct contact between the person experiencing the problem (customer) and person with most knowledge about the product (development).
- Usually after production start more than half a year goes by before the field feedback information is available in development.
- It is hardly possible to improve the field failure feedback flow, because the logistical pipelines cause that field feedback is too late anyhow.

Based on these conclusions, two improvement activities are proposed and tested. One concerns the statistical field information, and the other one concerns the engineering field feedback information.

Regarding the statistical field feedback information, it is proposed that the Warranty Call Rate, a metric that is used in industry to monitor the product quality/reliability, is replaced by a new developed estimator of the fraction products that fail within their first (say) year of use. The main advantage of this new estimator is the speed with which it gives an accurate estimate of the product reliability. Unfortunately, this new estimator cannot be introduced immediately, because first industry has to improve the performance of the field feedback information flow.

In order to speed up the engineering field feedback information flow, it is proposed to introduce a special test before the launch of a new and innovative product. Via an experiment it is proven that the proposed test shows a high ability of providing information that is valuable for finding root causes. The test also scores very high on the criterion speed of the feedback information flow. Using this test, valuable technical information about the root causes of field failures can be used for product quality improvements even before product launch.

Samenvatting

Gedurende de laatste decennia zet de combinatie van technologische innovatie en druk op time-to-market fabrikanten aan tot het verkorten van hun productcreatieprocessen. Om winst te kunnen maken, moeten fabrikanten als eerste op de markt zijn met producten met state-of-the-art functionaliteit, relatief hoge kwaliteit en concurrerende prijzen.

In hun poging om als eerste op de markt te zijn, hebben fabrikanten de neiging om ogenschijnlijk voor de hand liggende oplossingen te kiezen, bijvoorbeeld het laten vervallen van tijdrovende activiteiten zoals testen. Echter, als zulke drastische beslissingen worden genomen zonder een zorgvuldige analyse van de gevolgen, dan worden potentiële risico's over het hoofd gezien en worden onrijpe producten in de markt gezet. Deze risico's zijn extra groot voor hooginnovatieve producten, omdat door een combinatie van extra marktonzekerheid en technische complexiteit de kans dat een aspect wordt gemist dan veel groter is.

Dit levert een uitdaging op voor fabrikanten: hoe kan de kwaliteit van producten in de handen van de klant worden voorspeld, geëvalueerd en verbeterd. Dit vereist onder andere dat de fabrikanten data verzamelen over de werkelijke prestaties van de producten; met andere woorden: terugkoppeling van veldgegevens.

Het verzamelen en analyseren van informatieve veldgegevens over product reliability is het hoofdonderwerp van dit proefschrift. Het eerste deel van het proefschrift weerspiegelt de stand van zaken zoals beschreven in de relevante literatuur; vervolgens worden twee cases in detail bestudeerd; en tenslotte worden verbeteracties voorgesteld en in de praktijk getest met behulp van een nieuw en innovatief product.

De literatuurstudie levert de volgende problemen op:

- De componentgerelateerde informatie over productfalen beschrijft slechts een klein deel van de huidige faalmechanismen van consumentenelektronica.
- De snelheid van de huidige informatiestroom betreffende veldgegevens lijkt onvoldoende om de productkwaliteit tijdig te kunnen verbeteren.
- Volgens de beschikbare literatuur zijn de veldgegevens die nodig zijn om het faalgedrag van producten te kunnen bepalen, beschikbaar. Echter, gegeven het gebrek aan papers waarin de beschikbare veldgegevens worden geanalyseerd, zou de literatuur wel eens te optimistisch kunnen zijn.
- Informatie is alleen bruikbaar als deze op tijd beschikbaar is; daarom moet de snelheid van de terugkoppeling van veldgegevens worden onderzocht.
- De beschikbare voorspel- en analysetechnieken zijn voornamelijk gebaseerd op de veronderstelling van constante faalintensiteiten, hoewel deze veronderstelling gewoonlijk niet correct is.

Vervolgens worden twee cases gepresenteerd die demonstreren wat er mis is met de huidige manier van verzamelen en analyseren van veldgegevens: de veldgegevens worden niet tijdig teruggekoppeld en niet goed geanalyseerd. De casestudies worden uitgevoerd bij twee multinationale fabrikanten van consumentenelektronica. In deze

cases wordt veldinformatie onderverdeeld in technische informatie en statistische informatie. Technische informatie betreft de informatie die nodig is om de root cause van een probleem te kunnen vaststellen. Dit houdt in dat technische informatie essentieel is voor productverbetering. Statistische informatie betreft de frequentie van productfalen; dit type informatie is nauwelijks nuttig voor productverbetering, maar het geeft informatie over (sub-) populaties van producten en het vergemakkelijkt het doen van uitspraken over de overall productkwaliteit, bij voorbeeld in termen van de fractie producten die falen binnen de garantieperiode.

Tenslotte worden de eerder genoemde problemen geanalyseerd uitgaande van de technische veldinformatie en van de statistische veldinformatie. De resultaten worden vergeleken met de uitkomsten van de literatuurstudie. Dit levert de volgende conclusies:

- Hoewel de twee cases zijn uitgevoerd bij bedrijven met verschillende karakteristieken, lijken de terugkoppelsystemen die de bedrijven hanteren sterk op elkaar.
- De beschikbare veldinformatie is incompleet en niet geschikt om de root causes op te sporen en te analyseren.
- Er is geen direct contact tussen de persoon die het probleem ervaart (de klant) en de persoon met de meeste kennis over het product (de ontwerper).
- Het is vrij gebruikelijk dat de veldgegevens over de productreliability later dan een halfjaar na de productiestart bij ontwikkeling beschikbaar zijn.
- Het is niet goed mogelijk de terugkoppeling van veldgegevens te verbeteren, omdat de logistieke pijplijnen veroorzaken dat de veldgegevens sowieso te laat zijn voor kwaliteitsverbeteracties.

Gebaseerd op deze conclusies worden twee verbeteracties voorgesteld en getest. De ene betreft de statistische veldgegevens, en de andere betreft de terugkoppeling van technische veldgegevens.

Wat de statistische veldgegevens betreft, wordt voorgesteld om de Warranty Call Rate, een metriek die door de industrie wordt gebruikt om toezicht te houden op de productkwaliteit, te vervangen door een nieuw ontwikkelde schatter van de fractie producten die binnen (zeg) één jaar falen. Het grote voordeel van deze nieuwe metriek is de snelheid waarmee deze een nauwkeurige schatting geeft van de productreliability. Helaas kan deze metriek niet onmiddellijk worden geïntroduceerd, omdat de industrie eerst de terugkoppeling van veldgegevens dient te verbeteren.

Om de snelheid van de terugkoppeling van technische veldgegevens te verhogen, wordt voorgesteld een speciale test te introduceren die nog vóór de lancering van een innovatief product wordt uitgevoerd. Met behulp van een experiment wordt aangetoond dat de voorgestelde test de informatie kan leveren die van belang is bij het opsporen van root causes. De test scoort ook hoog op het criterium snelheid van de terugkoppeling van technische informatie. Met behulp van de test kan nog voor de lancering van het product technische informatie worden opgespoord die van belang is voor het verbeteren van de productkwaliteit.

Table of contents

Acknowledgements	i
Summary	iii
Samenvatting	v
Table of contents	vii
List of abbreviations	xi
Chapter 1 Introduction	1
1. Introduction	1
2. Thesis Structure	3
3. Definition of concepts	4
Chapter 2 Initial research proposal and observed constraints	7
1. Introduction	7
2. Initial research proposal	7
3. Approach	10
4. Results	11
4.1 Use of field failure information for quality and reliability analysis	11
4.2 Case studies	14
4.3 Field performance	21
5. Conclusions	22
6. Directions for redefining the research questions	22
Chapter 3 Research focus and approach	25
1. Introduction	25
2. Research design	25
2.1 Conceptual design	26
2.2 Technical design	29
3. Conclusions	33
Chapter 4 Market trends and their influence on the product quality and reliability information flow	35
1. Introduction	35
2. Market trends and their influence on product quality and reliability	35
2.1 Increasing product complexity	35
2.2 Longer warranty periods	36
2.3 Outsourcing and globalisation/segmentation of business processes	37
2.4 The impact of “time to market”	38
3. Market trends and their influence on the information flow	40

3.1 New demands on reliability prediction methods	40
3.2 Quality of information	41
3.3 Time required to obtain and deploy information	42
3.4 Describing information flows	42
3. Conclusions	45
Chapter 5 Field Feedback and its use for quality and reliability improvements	47
1. Introduction	47
2. Product Creation Process	47
2.1 Problems with the activities that assure high quality of products	48
3. Closing the loop PCP-Field: Field feedback	51
3.1 Field feedback: Deming cycle	51
3.2 Problems with field feedback loop of failures information, according to the available literature	53
3.3 Engineering information	55
3.4 Statistical information	56
4. Conclusions	57
Chapter 6 Field feedback of engineering quality and reliability related information	59
1. Introduction	59
2. Case High-End	59
2.1 Company introduction	59
2.2 Field feedback information flow	60
2.3 Conclusions case High-End	70
3. Case High-Volume	71
3.1 Company introduction	71
3.2 Field feedback information flow	71
3.3 Conclusions case High-Volume	80
4. Conclusions	81
Chapter 7 Field Feedback of statistical quality and reliability related information	83
1. Introduction	83
2. Point of departure	83
3. Warranty Call Rate	85
3.1 Warranty Call Rate: definition and characteristics	85
3.2 Warranty Call Rate: practical limitations	86
3.3 Need to estimate the WCR shortly after product launch	90
3.4 Discussion with respect to WCR	91
4. Estimating Weibull parameters	92
4.1 Weibull estimation for known sales dates	92
4.2 Weibull estimation for unknown sales dates	98
4.3 Discussion with respect to the estimation procedures	100
5. Conclusions	101

Chapter 8 Design and implementation of a new structure for fast and reliable field feedback	103
1. Introduction	103
2. Designing a fast and reliable information feedback flow	103
2.1 Present situation	103
2.2 Requirements	104
2.3 Basic model	105
2.4 New design for timely information feedback	105
3. Field test	108
3.1 Background	108
3.2 The test group	109
3.3 Test hypotheses	110
3.4 Results	111
4. Conclusions	114
Chapter 9 Conclusions and recommendations for further research	115
1. Introduction	115
2. Conclusions	115
2.1 Problem identification	115
2.2 Research question 1: what field failures information is vital for product development?	116
2.3 Research question 2: what field failures information do companies collect?	117
2.4 Research question 3: what activities can be performed to close the gap between needed and available field failures information?	118
2.5 General conclusion	119
3. Recommendations for further research	119
3.1 Can the results be generalised to a broader range of companies?	119
3.2 What is the optimal moment within a PCP to perform a field test?	119
3.3 Which criteria determine the composition of the test group and should these groups be constant in time?	120
3.4 How to combine field information with information that comes available during the PCP?	120
Appendix 1 Roller coaster curve	121
Appendix 2 Bathtub curve	123
Appendix 3 IRIS code	125
References	127
Curriculum vitae	133

List of abbreviations

BU	Business Unit
CC	Call Centre
CCC	Customer Contact Centre
CD	Copy Disc
CDR	Copy Disc Recorder
DB	Database
EFQM	European Foundation for Quality Management
FCR	Field Call Rate
FMEA	Failure Mode and Effect Analysis
FNF/NFF	Fault Not Found/ No Fault Found
IIC	Initial Investigation Centre
IRIS	International Repair Information System
ISO	International Organization for Standardization
MIL-HDBK	Military Standard Handbook
MIR	Maturity Index for reliability
ML	Maximum Likelihood
MP3	MPEG Audio Layer-3
MTBF	Mean Time Between Failures
MTTF	Mean Time To Failure
NSO	National Sales Organisation
PCP	Product Creation Process
Q&R	Quality and Reliability
QD	Quality Department
QFD	Quality Function Deployment
QFD	Quality Function Deployment
QPP	Subdepartment Quality of Products and Processes
RAC	Reliability Analysis Centre
RCA	Root Cause Analysis
RLC	Regional Logistic Centre
SC	Service Centre
SD	Selected Dealer
WCR	Warranty Call Rate

Chapter 1

Introduction

1 INTRODUCTION

In the last decades the combination of technological innovation and pressure on time to market results in price erosion and globalisation of the supply chain [Wyn99]. This as well as the increasing competitiveness on a global market put new demands on manufacturers of consumer electronics. To keep their positions and to make a profit, manufacturers have to be first on the market with products that have state of the art functionality, relatively high quality and competitive prices [Sta91], [Smi98].

In their efforts to be on the market as fast as possible, manufacturers tend to choose seemingly straightforward solutions like skipping time consuming activities such as testing. However, if such drastic decisions are taken without a thorough analysis of the consequences, possible risks are overlooked and immature products are put on the market [Ulr00].

Reducing the length of the product creation process requires perfect information and communication. An example is the concurrent engineering concept that comes down to performing many activities in parallel, what potentially reduces the throughput time of the product creation process. However, this makes high demands on the availability and sharing of information, and reducing uncertainty. A small imperfection in the information can lead to problems with the end product and, consequently, rework at the end of the process where it is most costly [Whe92]. A major obstacle in the communication and information deployment process is the globalisation of businesses and business processes, for example by outsourcing [Pet00b]. Globalisation implies that people in different parts of the world, with different backgrounds and cultural traditions work on the same project. It requires transferring information over big distances and reduces the quality of information exchanges. Outsourcing puts people with possibly very different goals and understandings in one product creation process [Wyn99].

Companies adopt quality programmes like ISO certificates and Customer Satisfaction programs in the hope that this, at least partly, solves their quality problems. One of the main problems with these programs is, however, that they passively describe procedures rather than actively contribute to product quality improvement. An overview on the problems that all those concepts bring about can be found in the literature. [San99]

Only lately it is reinvented that the contact with the customer is very important. A major step in that direction was the idea to integrate customer requirements into product development. This idea was first worked out in the 1970s at Mitsubishi's

Kobe shipyard. Under the name Quality Function Deployment (QFD) the idea has spread all over the world. In particular in the automotive industry QFD is a standard tool [Aka90]. Although the voice of the customer has been discovered, it is still not fully integrated in the Product Creation Process (PCP), this holds in particular at the back end.

Because of the high level of innovation and the pressure on time to market, zero defects are unrealistic in consumer electronics. As a result of these trends, products with structural uncertainty are put on the market. Only recently the consumer electronics manufacturers recognise the help they can get from the customers that use their product. These manufacturers initiate projects to get field failure information as a means to improve product quality. [Dom01], [Hey02], [Fra02].

Field feedback information can be subdivided into statistical information and technical/engineering information. Statistical information basically gives a review of the *frequency* of the problems that a company experienced. It is in particular relevant on management level for checking the overall product quality, for finding trends in product quality, for financial consequences likes warranty costs, etc. A disadvantage of statistical information is that it only takes into account the frequency of product problems, but not the root cause (for the definition of root cause, see section 3). In particular, if after product launch the first product failure is reported, this in itself does not give any indication about the seriousness of the failure. As soon as the root cause is known, the consequences of the problem in terms of warranty costs and customer satisfaction may become clear. Without knowledge about the root cause, sufficient statistical data is required before reliable conclusions can be drawn about the related warranty costs.

In general it can be stated that for quality improvement activities technical information about product failures is much more important than statistical information. Furthermore, technical information about each individual product failure might be used for product quality improvement activities, while statistical information is only valuable when enough information has been collected.

This leads to the following statement: If a company wants to improve its product quality, it should look first and in particular for the root causes of product failures.

A root cause analysis appears to get more and more complex with the increasing software share in consumer electronics products [Hey02], [Spr02]. In particular these software related failures, but not only these, are often reported as Fault Not Found (FNF), meaning that they cannot be reproduced in repair/service centres. This suggests that essential information about quality problems gets lost if there is no direct contact between the customer (as the person who experiences the problems) and the specialists from the company (as people with product knowledge).

The processing, generation, analysis and deployment of both statistical and engineering information is very relevant for companies. More and more companies realise that the presently available information is not suitable for product quality improvement [Bro00], and they try to improve the data collection (in terms of quality and speed), the metrics used, and the speed of analysing and using field information.

The problem of how to collect field failures information and how to process it in such a way that a company can use it for timely improvement of its products is also an interesting area to explore from a scientific point of view.

The speed of the field feedback has two aspects that are considered in this thesis:

- The field feedback should be fast enough to be of use for necessary improvements in current generation of products.
- In relation with the product road map, the field feedback should be fast enough to contribute to the prevention of recurrence of problems in new generations of products.

The consequences of dividing field information in two streams: statistical information about frequencies, and engineering information about root causes, have not yet been evaluated. This thesis deals with these aspects.

This thesis analyses the information flow from field to manufacturer from the point of view of information loss. Only when knowing the real weak points in the feedback information structure, improvements can be proposed. For this purpose this thesis analyses the information flows as observed in two companies from the point of view of information loss.

In brief, this thesis deals with the field information that companies need in order to be able to take product quality related decisions. This information is evaluated on the following criteria: availability, timeliness and relevance for quality improvements.

First, the available information is evaluated and compared with the information that is required for solving quality related issues in the consumer electronics industry.

Second, the length of time that it takes for field information to reach different departments in a company (development, manufacturing) is evaluated.

The end result of the thesis is a new strategy enabling companies to get the required field information at the right time.

2 THESIS STRUCTURE

CHAPTER 1 Introduction

This chapter gives an overview of the thesis.

CHAPTER 2 Initial research proposal and observed constraints

This chapter presents the initial research proposal as it was defined before the start of the project. Based on a literature study and three case studies the observed constraints are described and the reasons for redefining the research questions are given.

CHAPTER 3 Research focus and approach

This chapter defines the final research questions and the approach used to deal with them.

Also an overview of relevant available research methodologies is given and the argumentation for choosing one of them for this research.

CHAPTER 4 Market trends and their influence on the product quality and reliability information flow

In this chapter the current market trends in consumer electronics industry are described. Some of these were already mentioned in chapter 1, but in this chapter 4 they are presented in more detail and the relation between those trends and this research project is stated more clearly.

CHAPTER 5 Field feedback and its use for quality and reliability improvement

This chapter defines the scope of this research. It presents a review of the available literature about field feedback and gives the missing parts that are at the origin of this thesis.

CHAPTER 6 Field feedback of engineering quality and reliability related information

This chapter concentrates on the engineering information coming from the field. It evaluates the availability, timeliness and usability for finding root causes and improving products. The problems concerning this type of field data are analysed and a proposal for improvements is given.

CHAPTER 7 Field feedback of statistical quality and reliability related information

Here the statistical field feedback gets attention. Some available metrics, from the literature and from practice, are evaluated on speed and relevance for product quality improvements.

CHAPTER 8 Design and implementation of a new structure for fast and reliable field feedback

In this chapter the improvement proposal from chapter 6 is worked out, resulting in a new strategy for information gathering. The value of this new strategy is demonstrated in a case study. The results and a comparison of the results with the available structures for field feedback is presented. The comparison is, again, based on speed and suitability of the information for fast improvement of product quality.

CHAPTER 9 Overview, conclusions and recommendations for further research

This chapter gives an overview of the whole thesis. Consecutively it presents the main conclusions of the research. To close, it gives directions for further research.

3 DEFINITION OF CONCEPTS

In this section definitions are given of most relevant concepts.

- Customer – A person who uses a product that did not produce it himself.
- Engineering Information – The information that is necessary in order to be able to detect the root-cause of a product failure.

There is a relation between the definition of quality (cf. quality) and the definition of engineering information. If a customer reports a failure, the product might still satisfy the technical specs. In such a case a repair centre will report: fault not found. If the product does not satisfy the technical specs, then it makes sense to start a root cause analysis. The root cause can be in the product, but can also be caused by customer use. In this thesis engineering information covers all aspects that are relevant to understand the reason why a customer reports a product failure.

- Failure Rate – During the life of non-repairable items the failure rate $\lambda(t)$ is the instantaneous probability of the first and only failure [OCO02].

In formula:

$$\lambda(t)=f(t)/R(t)$$

where:

t – relevant lifetime characteristic (like calendar time, or time in use)

f(t) – probability density of the relevant lifetime

R(t) – reliability/survival function

- Field Feedback – The information related to the performance of products in interaction with customers.
- Innovative products – Products with a basically new functionality or product design.
- Product Failure – Situation where the customer decides to report the fact that the product is not able to meet the explicit and implicit requirements of the customer. Product Creation Process (PCP) – A process that systematically transforms new product ideas into a set of products that can be used by end users or that serve to manufacture new products.
- Quality – The total features and characteristics of a product or service that bear on its ability to satisfy given needs [Lew96]. In this thesis Quality refers to the product features and characteristics at the time of sales. As soon as the product behaviour as a function of time is discussed, then the word Quality should be replaced by Reliability.

In the framework of this thesis there is a conflict between the customer's point of view: '... the quality of a product depends on how well it fits patterns of consumer preferences' [Kue62], and the manufacturer's point of view: 'Quality is the degree to which a specific product conforms to a design or specification.' [Gil74].

The difference between these two definitions has consequences when the customer reports a product failure. The customer might report a failure, while the repair centre is of the opinion that the product is within the technical specifications. As a result the repair centre might report that the fault was not found.

- Reliability – The probability that a system will perform its intended function for a specific period of time under a given set of conditions [Lew96]. In order to avoid that too much rigidity makes this thesis unreadable, usually, when there is no confusion possible, the word quality is used in a general sense, meaning reliability as well.
- Root-cause of a failure – Most basic causal factor or factors that, if corrected or removed, will prevent recurrence of the failure.
- Statistical Information – The quantitative information about the frequency of product failures, meant for statements about (sub-) populations of products.
- Time-to-market (TTM) – The length of time it takes to develop a new product from early initial idea to initial market sales [PDM03].

Initial research proposal and observed constraints

1 INTRODUCTION

This chapter deals with the initial research proposal. Here I describe the research questions as they were defined before the start of my project and I explain my initial research based on this research proposal.

I describe the research questions in section 2. In section 3 I explain the approach used to conduct the initial research. In section 4 the relevant facts and figures are presented. Finally, in section 5 I present the conclusions of my initial research. These conclusions give rise to formulate a new research question; section 6 introduces this new research question and describes the contents of the rest of this thesis. The new research question is discussed in detail in chapter 3.

2 INITIAL RESEARCH PROPOSAL

Companies in the competitive market of consumer electronics are confronted with a number of threads [Gra01]:

- Because of the high innovation speed, many products are obsolete in a few months. This leads to price erosion.
- As a result of the competitive market the profit margins are low. Together with the price erosion, this forces companies to launch new products as fast as possible. Only when a product is first on the market is it possible to make a profit.
- More and more parts of the product creation process are outsourced to subcontractors in different parts of the world (globalisation). This puts pressure on the product quality and requires new information and communication systems.
- For innovative products with new functionality it is not always clear how customers will use the product, and therefore it is not possible to come up with a dedicated test programme. Nevertheless, customers require a high product quality level, which is in conflict with the time pressure and the high innovation degree.
- Enforced by legislation the warranty time and coverage increase. This translates product quality problems in financial losses.

In order to be able to quantify the risks that result from these threads, an accurate product reliability prediction model is needed. One of the most commonly used reliability models is, and was for many years [MIL65], the so-called constant failure rate model. In this model the failure rate of a product is determined as the sum of the constant failure rates of the components. The advantage of this model is, that it allows a very simple product reliability analysis. This model is based, however, on three assumptions:

- The failure rate of a system is determined by the failure rates of the components.
- The failure rates of the components are constant in time.
- Products are statistically seen identical (for example, from batch to batch).

This model has already been criticised in [Sho68]. More recently, for example [Wong88] and [Bro92] have shown that in several branches of electronics industry, especially in the areas with a high degree of technological innovation, the assumptions mentioned above are not fulfilled.

Figure 2.1 shows an example of the results of a field study [Bro92] where the reliability field performance of components in a high-volume consumer product was compared with the predictions using a number of prediction handbooks, such as the MIL-HDBK217 [MIL87] and the British Telecom HRD4 [BT87] ¹. One of the observations of this study was that in product A the existence of a bimodal distribution for certain critical component parameter caused for a sub-population with a strong deviation in failure behaviour.

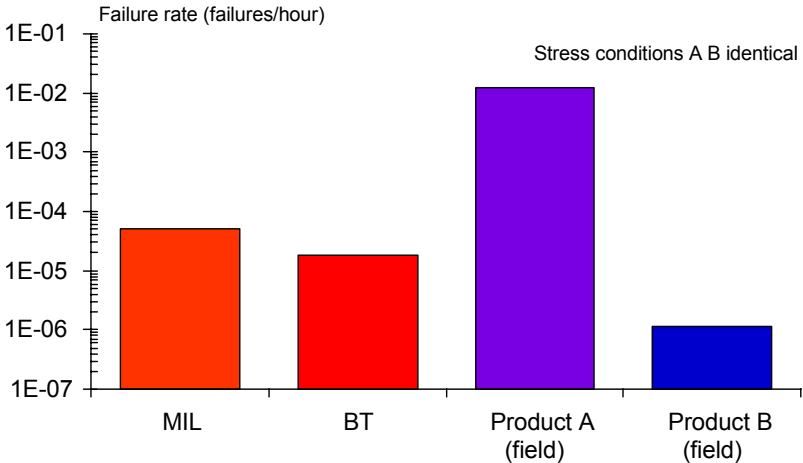


Figure 2.1: Observed differences between predicted and actual failure rates [Bro92]

¹ The left two columns in figure 2.1 represent the failure rate according to the MIL and the British Telecom reliability prediction handbook; the right two columns are failure rate figures from two different, but for the handbooks identical, products.

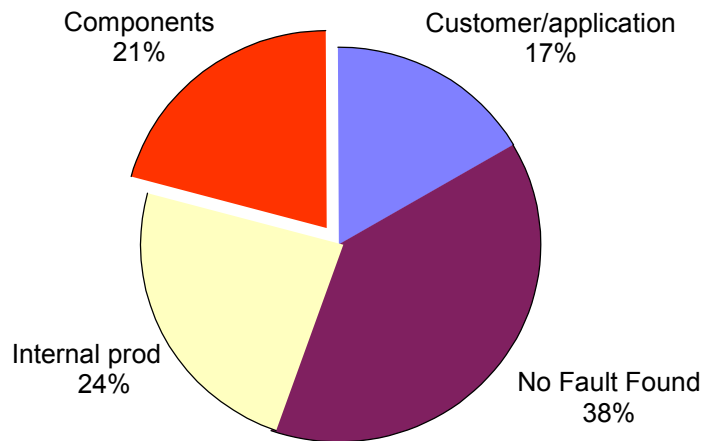


Figure 2.2: Observed categories of reliability problems [Bro96]

Figure 2.2 shows an example of the results of a later study [Bro96] where the reliability failures in products were split in problems on component level, problems on “internal product level” (e.g. interaction problems) and problems on “customer / application” level. This analysis showed that the largest group consists of failures for which the cause of the failure remained unknown. The category “internal product level (not components)” and the category “problems on customer / application level” were comparable in size with the, traditional, component related failures.

These observations establish that reliability prediction models that are based on constant failure rates of components are not realistic for consumer electronics industry. This leads to the conclusion that companies in the electronics industry are confronted with the following situation:

- The ‘old’ reliability prediction method has no sound basis any more within the consumer electronics industry.
- Only a minor part of the root cause of product failure can be attributed to components, since for a considerable fraction of product failures the root cause may be unknown.

This suggests that it makes sense to explore the possibility of extracting more product quality related information from the field and bringing this information as fast as possible to the manufacturers in order to enable them to improve the product quality of the present and future generations of products. Next, new reliability prediction models should be based on this field data.

This line of thinking resulted in a research proposal named Developing Predictive Reliability Models Based on Field Feedback Information Flow Analysis. The objective of the proposal was to develop a new reliability prediction model that would be suitable for the consumer electronics industry. The first step of the proposal was to analyse on response time the statistical information and the reliability metrics used in the consumer electronics industry for evaluating the field performance of the products. The possibility of finding the real failure mechanisms based on field information should be explored.

Part of the plan was to analyse and improve the field feedback process as well as the deployment of the field failure data provided by industrial partners. Based on prior information from these partners it was assumed that the necessary field data was available and suitable for analysis.

3 APPROACH

In order to understand the research question and the context, first the relevant literature was studied and next some industrial partners were visited.

The literature study concentrated on the product creation and utilisation process, in particular on development, production and service/repair. The most relevant aspect was the required information from the point of view of product quality and reliability and the timeliness of the feedback information flow for decisions with respect to the following two questions:

- Is the product quality reason for a product recall? (There are three possible motives for a product recall: 1. liability, for example in case of a safety problem; 2. product quality in the sense of (lack of) customer satisfaction, for example when the product performance is far below customers' expectations; 3. costs as a result of low reliability, for example when there are strong indications that the warranty costs, including the logistics costs of spare parts management, will exceed the costs of a recall.)
- On what aspects should the product quality, in the broad sense (see chapter 1 section 3) be improved?

These questions require statistical information, like the percentage of failures within, for example, the warranty period, and engineering information about for example, failure modes. In general it can be stated that a reliability prediction model should be based on a combination of statistical characteristics, like lifetime distributions, and engineering characteristics, like potential failure modes.

The industrial partners were selected in such a way that they represented different parts of the electronics industry (see section 4.2). They were visited in order to define the required information, to investigate the existing field information and the information flow, as well as to detect the way the available information was analysed and the results were used.

The companies that were visited were confronted with the following five questions:

- Is there a product quality oriented field feedback system?
- If there is a field feedback loop; does it generate the required statistical and engineering information?
- Is the collected field information suitable (also taking into account the timing of the PCPs) for quality and reliability improvement purposes?
- Is this field information analysed correctly and in relation to the goal?

- Is the information used for product quality improvement?

It would have made sense to investigate the deployment of the information as well, but because this subject was explicitly formulated as the research assignment of another PhD student, it was left out of consideration.

These five questions are further discussed in section 4.1.

4 RESULTS

Section 4.1 concentrates on the five basic questions of the initial research and gives an overview of the available literature. The section 4.2 and 4.3 are based on field information. Three companies have been visited with the aim to learn and understand their performance with respect to the five basic questions. The general characteristics of these companies are presented in section 4.2. Their specific performance with respect to the five basic questions is given in section 4.3.

4.1 Use of field failure information for quality and reliability analysis

Many authors discuss the role of engineering and statistical information for quality and reliability improvement. The overall relevance of information is given in Blanks [Bla98]. He explains the need of quantitative reliability data by mentioning the significance of this data for decisions about a wide range of topics. He mentions optimisation of system constitution and operating and maintenance procedures, specification of the required reliability, comparative product and design evaluation at the time of procurement, planning and sustaining maintenance and logistic resources, institution of optimum preventive maintenance procedures and frequencies, detection and correction of reliability problems in the operation of equipment under user control, implementation of guarantee and reliability incentive schemes, determination of optimum replacement or overall time of aging equipment.

In the following I concentrate on the information aspects from the perspective of the five basic questions as given in section 3. First each of these aspects is briefly explained.

4.1.1 Existence of product quality oriented field feedback system

It is to be expected that companies dealing with consumer electronics collect relevant information about the field behaviour of their products. For sure these companies collect financial information about warranty costs; and for sure they collect logistic information about the type and number of spare parts that are required. This is confirmed in my discussions with industry.

However, it cannot be taken for granted that companies also collect accurate information about product quality aspects like root causes of field failures as a function of product use. Therefore it has to be investigated whether companies have a product quality oriented feedback system. If the answer is positive, then the next

question is, of course, whether that feedback system is adequate. The next four question refer to this aspect.

4.1.2 Availability of the required statistical and engineering information

There are different reasons why essential information is not available. For example:

- The product quality problem has not been clearly defined, therefore it is not known why and what information is required.
- It might be extremely difficult to collect the required information. Example: after the warranty period it is far from easy to collect representative field information about product reliability [Bli94]. (In section 4.2 it is mentioned that one of the companies I visited is able to collect this information.)
- The required information may be available ‘somewhere’ in the company, but the information flows are not structured in such a way that the information is available at the right place and the right time, and therefore the information cannot be used [Güt99].

4.1.3 Suitability of the information for the goals

A product is developed to do its job under well-defined conditions. Accordingly, the number of product failures depends on the actual conditions in the field. If a company collects product quality information without taking into account the conditions in which the product operates, then valuable information is lost. Analogously, if a company wants to know the root cause of a field failure in order to prevent these failures from recurring, then it does not help much if only the number of failures is counted.

If the essential information is in principle available, but did not yet reach the people who should use it, then there is a problem with the speed of the information propagation. Example: if a product is repaired in a repair shop and the root cause of the product failure has been detected, it might take several months before the information about the root cause of the defect reaches the designers. All these months the designers feel free to use the same design in new products [Smi98]./This is visualised in Figure 2.3.

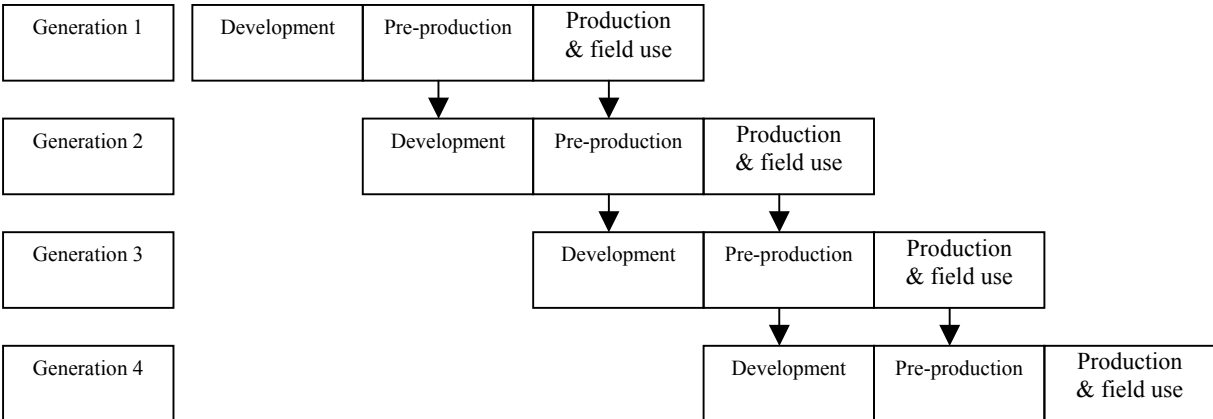


Figure 2.3 Example of an industrial roadmap

Figure 2.3 demonstrates that if field information on product generation (1) becomes available during the production of product generation (2), then preventive actions are to a limited extent possible in generation (3), but to a full extent only in generation (4).

Information analysis

It does not make sense to collect and analyse data without a well-defined purpose. Depending on this purpose, a suitable model should be chosen. If the wrong model is used, most likely the result of the analysis becomes compromised.

- **The analysis depends on the purpose.** Example 1: the Maturity Index on Reliability has been developed with the intention to *classify companies* based on the quality of their information flows [Bro99]. Example 2: [Mol94] introduced the M(t)-graph as a means to *describe the failure behaviour* of a population of products. Example 3: Anderson and Fagerhaug [And00] analyse information in order to *find the root cause* of an individual product.
- **The analysis depends on the chosen model.** Example 1: prediction of the field reliability of a product is often based on [MIL65]. This method has been criticised, see among others, [Sho68], [Bro90], [Pec94]. The main argument is that the [MIL65] methods are based on a constant failure rate. In particular [Won81, [Won88], Won91] argue that in the electronics industry the failure rate is more likely to follow a roller coaster shape.

Use of information for product quality improvement

Even if the right data has been collected and is analysed in the right way, it cannot be taken for granted that the generated information will be used. For example, lack of time or lack of resources may cause that actions to prevent the recurrence of a particular well-known root cause are postponed indefinitely.

Conclusions

From this section the following can be concluded:

- The standard reliability prediction model is based on unrealistic assumptions that do not match the failure behaviour of consumer electronics.
- Field failure information may be helpful for improving product quality and finding useful reliability prediction models.

Because manufacturers of consumer electronics claim that they collect product quality oriented field failure information, a logical next step is to visit a few of these manufacturers in order to see what the actual situation is: do they collect the field information with a clear picture of the purpose, do they analyse the data in the right way, and do they use the results? This is the topic of the next section.

4.2 Case studies

In order to study the structure of the field feedback flow, as well as the quality and speed of this flow, it was decided to visit three companies² that already used product quality oriented field feedback flows. The field feedback flows of these companies were evaluated, emphasising the structure of the feedback flow, the timing aspects, the available sources of information, and the contents of the collected information in relation to the information need.

In this section an overview is given of the different field feedback processes. The consequences of the field feedback process for the answers on the five questions (section 3) are given in section 4.3.

As the three companies use more or less the same overall structure, only this common structure is given. Some individual details are presented where this is informative.

4.2.1 Analysing the structure of the three companies

The first company can be described as a high volume consumer electronics company. In this thesis it is denoted as High-Volume. As this company is strongly cost driven, it outsources all product repair activities. The repair centres are only paid for repairing products and not for looking for root causes of product problems, what results in a very limited amount of useful field feedback information.

The second company is a low volume high-end consumer electronics company. It is denoted as High-End. Customer satisfaction has a high priority. This means, for example, that High-End has a 'fairness' strategy: also after the (two-year) warranty period many problems are handled as warranty repairs. About 20% of all repairs belong to this category. This strategy does not only contribute to customer satisfaction, a consequence is also that product reliability data becomes available over a period of several years. High-End is very much interested in field feedback information, in particular in root cause analyses, but the right organisation structure and the right field feedback process have not yet been found. This conclusion is made by the author and agreed with High-End.

The third company is a low volume professional electronics company (denoted by ProF). This company sells professional products for providers of telecommunication facilities. If the availability of these products is not close to 100%, ProF is confronted with substantial penalties; therefore product repair actions need to be fast, what is an obstacle for root cause analyses.

These three companies were chosen because they are all aware of the value of a product quality oriented field feedback system and they all use such a system.

The field failure feedback processes of the two consumer electronics companies have been studied in detail; the field failure process of ProF is mainly studied to find out whether the field failure feedback processes for consumer products and for

² For confidentiality reasons the names of these companies cannot be displayed.

professional equipment are more or less similar. The conclusion is that there are no serious differences between the three companies as far as field feedback is concerned, although there are quite a few minor differences. Findings of other research about field feedback processes, [San00], support the feeling that the three case studies give a fair representation of the situation in consumer electronics.

4.2.2 Aspects dominating field feedback

In my analysis of the situation in industry, it became clear that given the circumstances, see section 4.1, it is more or less impossible to guarantee that a new product meets the customers' requirements. Therefore the companies have very high expectations from field feedback loops. In order to be able to analyse the field performance of their products in the hands of the customers, all three companies want to have a very fast indication of field problems, in order to be able not only to prevent the recurrence of old problems in future products, but also to improve current products. Their interests concentrate on detecting root causes of technical problems and predicting the warranty costs. In section 3 I gave three relevant reasons for a company to be interested in product quality: liability, customer satisfaction and costs. In general the main driver of the three companies is on costs. This is in particular true for High-Volume. ProF is the only company with a real interest in liability; the reason is that its customers demand compensation for the time that the product is not available.

The interest in field information is, of course, partly due to the fact that product quality improvement leads directly (less spare parts) and indirectly (hidden costs) to cost reduction.

In particular for the companies High-Volume and ProF the speed of the feedback information flow is very relevant. This is a direct consequence of the considerable reduction of the throughput time of the product creation process (PCP) during the last 10 years to only a few months for most products at the moment. Example: during the last few years the PCP cycle of monitors has been reduced from 2 years to 18 weeks. The speed of the information flow is less urgent for company High-End, because High-End's PCPs have much longer throughput times than the PCPs of the other two companies. However, High-End is confronted with an increase in number of competitors and recognises the need of reducing its PCPs in order to stay competitive. This is discussed in more details in chapter 6.

As mentioned in chapter 1, shorter development times, more complex products and the expanding cooperation with suppliers make it increasingly more difficult for manufacturers to assure product reliability. These trends can be clearly seen in the three companies that were visited. All three companies, no matter the length of their PCP, want to have the field feedback earlier in order to be able to predict the product behaviour as early as possible and to act appropriately.

4.2.3 Field feedback loop

In order to get a better idea about the quality and the speed of the field feedback flow, a logical first step is to map the feedback flow and to identify the possible sources of information.

It appeared that irrespective of the differences between the companies' characteristics, the differences between their feedback processes are small.

Figure 2.4 presents the common structure of the field feedback flow for all three companies.

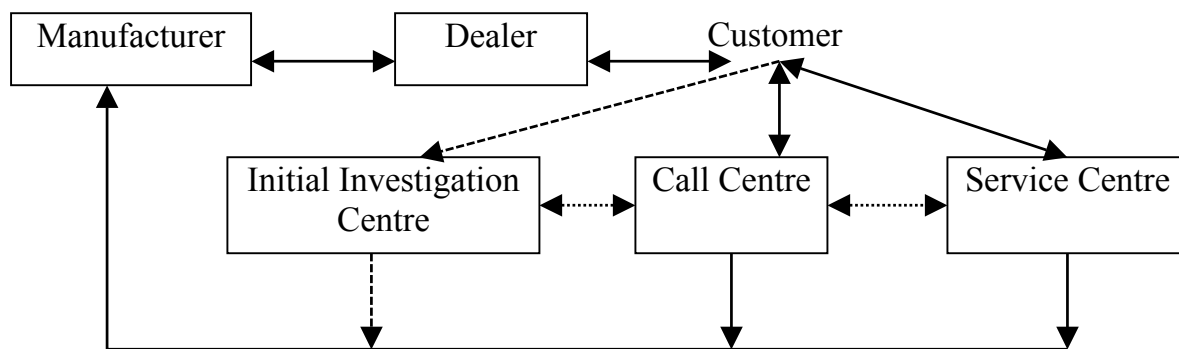


Figure 2.4 Field Failure Feedback Information Flow

Of course there are some differences between the three feedback flows, but these concern details. For example, High-End uses the Initial Investigation Centre (IIC) in the following way: each time a serious product quality problem shows up in the field, a dedicated team is set up of specialists from Development, Production and the Quality Department. The situation is different in High-Volume, moreover, during my study there have been relevant changes in the position of IIC in High-Volume. These changes are interesting enough to describe. The following happened. At the start of my study High-Volume had four independent Initial Investigation Centres spread over Europe. When a new product was put on the market, the responsible Quality Manager could decide that the first, say, 100 failed products had to be sent to an IIC for a root cause analysis. At the beginning of my study High-Volume closed three of these IICs, and more recently they closed the last IIC as well. (This explains the dotted line in figure 2.3). Repair shops now handle all repairs. However, these shops are only paid for repairing products at minimal costs, what implies that these repair shops do not look for the root cause of a problem; they just replace modules or even whole products. As a result, High-Volume no longer has the facilities to collect root cause information from the field. The reason for this decision was to cut down the direct expenses. Apparently, at the moment the short term reduction of the expenses is more important for High-Volume than the potential future cost savings by a reduction in warranty costs and an increase in market share as a consequence of a high product quality.

The next sub-sections identify the sources of information that are relevant for the research problem, but a full discussion about the merits of them is postponed to the next chapters, where each of the sources of information is discussed in detail on the speed of the accompanying information flow and the relevance of the provided information in relation with quality improvement.

4.2.3.1 Dealer

When a customer encounters a problem with his product, he can contact the dealer. Besides selling the product, the dealer's task is also to forward questions about products with technical problems to a repair shop (some dealers have their own repair shop) and to answer non-technical problems, if possible, or else to forward the customer to a Call Centre (CC). A customer can contact a dealer for different reasons and the dealer has three standard options.

- *Give general information:* An answer to a specific question or assistance to handle the device. The salesman usually has enough product knowledge and general experience to answer many questions or to explain to the customer how to use his device. If necessary the dealer can ask a CC for information.
- *Escalation to the National Sales Organisation:* This is done in case of difficult and serious questions, missing parts, or products that are dead on arrival. The National Sales Organisation will support and supply the dealer on the one hand and report the issue to Customer Interface on the other hand.
- *Repair Request:* When the dealer gets the impression that the product needs a repair, he will send the device to a repair shop, often called Service Centre. This repair shop might be owned by the dealer, might be a company's (central) repair shop or a third party.

The three companies do not register the contacts between customers and dealers and no feedback to the manufacturer exists. The manufacturer only indirectly takes note of these contacts in case a specific contact leads to a repair or to a call to a CC.

It was investigated by others as well [Mol99] that the dealers hardly give valuable feedback that can be used for quality improvement. A reason behind this is that a dealer is mainly interested in satisfying his customers and less interested in helping the manufacturer. This also explains why information coming from a dealer is not always reliable.

This situation is very well known within the three companies, and the dealers are not even considered as potential suppliers of quality related information. This is to a certain extent not true for High-End, as it has its own dealers who do not sell other brands, and High-End includes part of these dealers in the process of collecting quality related information.

4.2.3.2 Initial Investigation Centre (IIC)

During my study the IIC of High-Volume generated more product quality related data than the IICs of the other companies. This was a consequence of High-Volume's

policy that for innovative products, IIC had to look for the root cause of the first 50 to 80 devices brought in for repair. Unfortunately, an analysis of the data demonstrated that, in general, it took more than 6 months before the by IIC collected data reached the Quality Department of High-Volume. The conclusion is that this information flow is much too slow (these aspects are explained in more details in chapter 6).

4.2.3.3 *Service Centre (SC)*

The task of a SC is to repair failed products. All repair actions executed by Service Centres are recorded in jobsheets. A jobsheet contains the serial number of the product, a description and the position of the replaced module or component, and a description of the repair action. All jobsheets together with the warranty claims are sent to the quality department (QD). The jobsheets notify the QD about all replaced modules and components. This data is not very informative from the perspective of product quality improvement, because the repair manual only prescribes to replace a module, it does not prescribe to look for the root cause of the module, or even to look for the failed component.

It is interesting to note that figure 2.2 was based on jobsheet information, because jobsheets show which parts/modules were replaced/repared. It is also interesting that an analysis of a professional product of ProF revealed that for that product the distribution of the observed reliability problems match the distribution given in figure 2.2: 18% of the reliability problems could be traced to component problems, and for 49% of the reliability problems the conclusion was: Fault Not Found.

The jobsheets are also used for metrics like the Field Call Rate (FCR). The FCR is a common reliability metric that gives a moving estimate of the probability that a product will fail within one year after sales. The FCR is discussed in detail in chapter 7. It is often used in consumer electronics, but more and more it is recognised that the FCR is not very useful for quality improvement purposes [Pet00a], [Ion03]. For now I only mention that during the initial investigation it was observed that usually a more or less reasonable indication of the FCR cannot be made during the first six months after commercial release of the product.

It is remarkable that so many failures belong to the No Fault Found (NFF) category; these failures have been observed by the customer but cannot be reproduced when the product is brought for repair.

If a particular problem is found frequently, a Customer Complaint is filled out. It indicates that the problem might be epidemic and has to be solved urgently. Those customer complaints are investigated with priority. The activities are focussed on finding the root cause of the problem.

In order to get an idea about the speed of the information flow, for a particular High-Volume product all jobsheets about the first 24 weeks after production were investigated. As said before, all devices brought in for service are reported in jobsheets. There is, however, a delay in reporting these jobsheets, because service centres do not have to report these jobsheets immediately. They get paid for warranty claims as long as the jobsheets are reported within three months after the repairs.

Figure 2.5 shows the number of failed products per week, based on the jobsheets. Week one is the first week after production start.

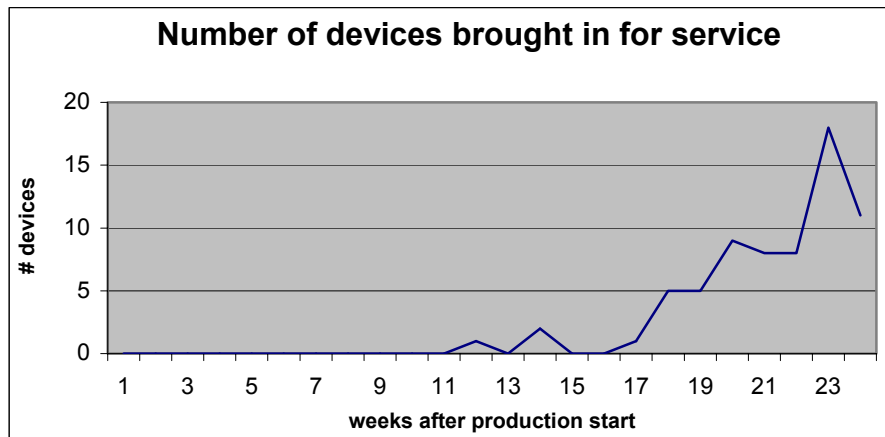


Figure 2.5 Number of devices brought in for service as a function of time

(Figure 2.5 gives the result for a particular product, but the pattern is representative for many regular high-volume consumer products.)

As can be seen, the first device was brought in 12 weeks after production start, and during the next twelve weeks the number of incoming devices increases per week. In the last week the number of reported failures decreased. Most likely, this is not because fewer devices were brought in for service, but because not all services were already reported at the time of my investigation. From production start it took 20 weeks until 20 devices were brought in for service.

An important aspect is, of course, the throughput time of the feedback from the Service Centres to the Quality Department. It could be traced that from the date of the production start, it took at least 28 weeks until the Quality Department received the first feedback in the form of a jobsheet. In other words, it took more than half a year before the Quality Department got feedback about the field behaviour of a new series of products.

4.2.3.4 Call Centre (CC)

If the jobsheets come in later than six months after production start, it certainly cannot be called *Fast Field Feedback*. Therefore it is interesting to examine how long it takes until customers start reporting problems to a Call Centre. In order to give a complete picture about the throughput time for at least one product (according to the manufacturer the situation for this product was in line with the situation for other products), it was investigated what the average time is between production date and problem report date for the same type of products as the one used in figure 2.5. From 1,316 problem reports the time between production date (gained from the serial number) and purchasing date (gained from the receipt) is calculated. The result is presented in figure 2.6.

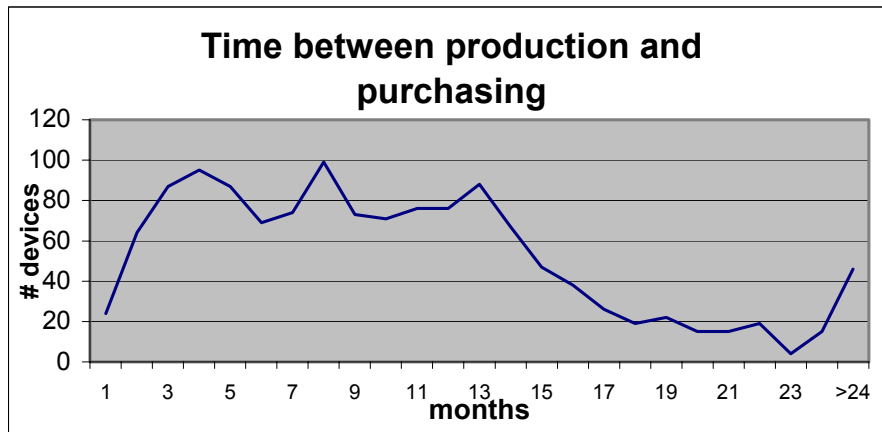


Figure 2.6 Time between production and purchasing

Note: Data about the production date, the problem report date, and the time in use can be used to analyse the relation between the reliability of a product and the production date.

From figure 2.6 it can be derived that only 32% of all products are sold to the end users within six months after the device was produced. It was also calculated that only 17% of all products that were produced during the first six months after production start were sold during these same six months.

These figures suggest a long delay between production start and customer complaints, therefore the time between purchasing date and problem report date was investigated for the same 1,316 products. The result can be seen in figure 2.7.

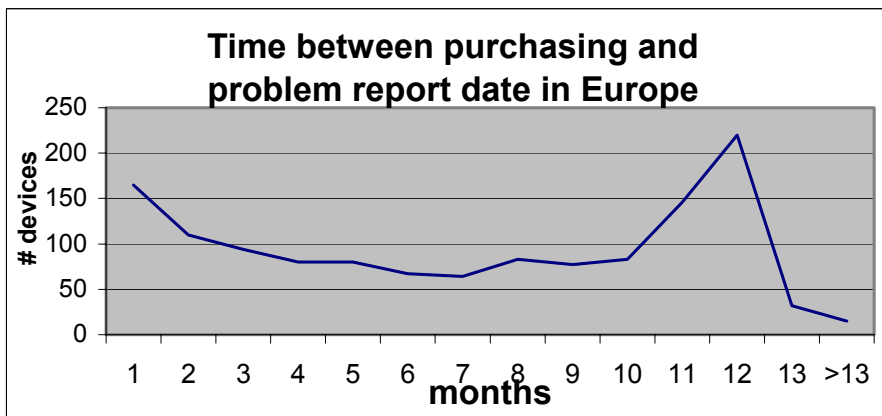


Figure 2.7 Time between purchasing and problem report in Europe

From figure 2.7 it can be derived that 45% of the problematic devices fail within their first six months. The graph shows a peak in the eleventh and twelfth month: 28% of the problematic devices were brought in, in the eleventh or twelfth month. These customers bring their device back just before the guarantee period expires. The problems are probably (small) problems, which the customers encountered earlier,

and could live with. They bring the device back, because the problem can be repaired free.

Summarizing, it can be said that in the situation discussed above, in 68% of the cases the pipeline alone exceeds 6 months. The time between the purchasing of a device and the moment at which the device is brought in for repair is more than half a year in 55% of the cases.

4.3 Field performance

In this section I summarise the performance of the three companies with respect to the five questions of the survey.

Is there a product quality oriented field feedback system?

All three companies have a field feedback information flow, but these flows are more tailored to the collection of warranty costs and spare parts management than to product quality information that is valuable given the high innovation degree. This holds in particular for High-Volume. Looking at the three aspects: liability, customer satisfaction and costs, it can be stated that all three companies focus their field feedback system on (warranty) costs and spare parts aspects. Liability/safety is not a standard aspect of their feedback system, and the same holds for customer satisfaction. For High-End this is surprising, because customer satisfaction is their main driver.

If there is a field feedback loop, does it generate the required statistical and engineering information?

All flows generate some information about the number of replaced modules and hardly any information about root causes. Consequently the contribution to product improvement is limited, partly because of the long throughput times between production and the availability of the field information in Development. High-End performs a bit better than the other companies, mainly because of the position of the IIC.

Is the collected field information suitable (also taking into account the timing aspects) for quality and reliability improvement purposes?

In particular the information about the number of replaced modules that is collected by all three companies has hardly any value for product quality improvement. The collected root cause information has its value, but unfortunately this information is usually rather late. The delay in the feedback has caused the long throughput times between production and the availability of the field information in Development.

Is this field information analysed correctly and in relation to the goal

High-End and ProF are more focused on using field feedback for product quality improvement than High-Volume. Given the different positions of the three companies, this is not surprising. High-Volume is obviously more cost driven and focuses on the development of highly innovative products. High-End concentrates on a niche in the market; innovation is becoming more and more important, but customer satisfaction is still the main driver. For ProF the availability (= fraction up-time) is

number one; if there is a product failure, then it has to be repaired as fast as possible. This has as a result that a root cause analysis is not always possible. Maybe this explains why we found 50% Fault Not Found (section 4.2.3.3).

Is the information used for product quality improvement?

The overall conclusion is that all three companies struggle with the introduction of a product quality oriented field feedback. They do not succeed very well in collecting the required information about field failures, and the field feedback information flow is far too slow given the required innovation degree.

5 CONCLUSIONS

- The value of field data depends on the goal. In general it can be said that statistical data is suitable for questions on management level, while engineering data is relevant on operational level.
- Field data about product failure behaviour is not clearly classified in statistical and engineering information.
- The field feedback flows focus on logistics and warranty cost related field data.
- The available field data is hardly suitable for product quality improvement.
- For the case discussed in this chapter, in 68% of the cases, the pipeline alone exceeds 6 months. In 55% of the cases the time between the purchase of a device and the moment on which the device is brought in for repair is more than half a year.
- The field feedback flow appears to be too late to be useful for quality improvement activities, given the short product creation processes.
- The field feedback flow gives incomplete data about the root causes of product failures.

6 DIRECTIONS FOR REDEFINING THE RESEARCH QUESTIONS

This chapter evaluates the speed and the usability of field data for product related quality improvement. In particular because of the current short PCP cycles, the relevant information must be available as soon as possible. It has been demonstrated that the available field data is not complete and not suitable for product quality improvement activities.

Because of the foregoing, the research question should be shifted from analysing the available field data towards analysing why companies do not collect the right product quality oriented data, and why the field feedback information flow is so slow. Only if the answers to these questions have been found, it is possible to find a solution in a structured way.

A logical approach should make a clear distinction between engineering related field feedback and statistical field feedback. Engineering related information can be collected, as it will be shown later in the thesis, within very short time intervals. This kind of information has real potential in enabling product quality improvement, as it focuses on finding the root cause of product failures. This information is relevant on operational level. Chapter 6 deals with this aspect.

The collection of statistical information takes much more time, as statistical analyses require that enough product failures have been observed. Statistical information is in particular relevant on management level, for example for questions like: do we learn from the past? In other words: is the product quality of the more recent products better than the product quality longer ago? Or: more specific: what warranty costs do we expect? Statistical information is of limited value for product improvement activities; these activities require engineering information.

The remainder of this thesis concentrates mainly on collecting engineering information that is relevant for root cause analyses, and collecting it fast enough given the short PCPs.

There is only one aspect of statistical information that is analysed, and that aspect concerns metrics that are suitable for monitoring the reliability performance of products. The reason for this is that the companies High-Volume and High-End both use a metric that is provably unfit for its task: give an accurate estimate of the product reliability performance (mainly in order to be able to give an early forecast of the warranty costs). This metric, the warranty call rate, is extensively discussed in chapter 7, and a promising alternative is given.

Chapter 3

Research focus and approach

1 INTRODUCTION

A consequence of the conclusions of chapter 2 was that the initial research focus and approach had to be reconsidered. The purpose of this chapter is to define the final scope and content of the research. The part of the problem domain on which the research will focus is defined, the research aims are stated and the resulting research questions necessary to achieve the aims are presented. First the general approach to, and design of, the research is discussed; thereafter the detailed structure of the thesis is outlined.

2 RESEARCH DESIGN

Research designs are meant to structure a research. For this reason an explanation of the available literature on this subject is presented. Consecutively a research design strategy is chosen and the reasons for this choice are given.

Many books have been written on the subject of research methods, e.g. [Str90], [Bel81], [Yin94]). Each of them concentrates on one or more research methods. However, there is far less material available on the problems a researcher encounters when he is engaged in the process of designing a research project. As choosing a research method is only a part of all the issues that should be looked upon in a research, a more general approach to the subject must be used in order to be able to handle all the aspects of the research.

The design of the present research follows basically the methodology proposed by [Ver99]. This methodology structures the complete process through which this research is conducted. The methodology about research designs given by [Ver99] gives a clear explanation of the differences between theoretical and practical research, and it has been chosen because the research presented in this thesis has elements of both theoretical and practical research.

According to [Ver99] every research design consists of a conceptual and a technical phase. Each of these phases together with the steps in which they are performed can be seen in figure 3.1, and these steps are explained in the following sections.

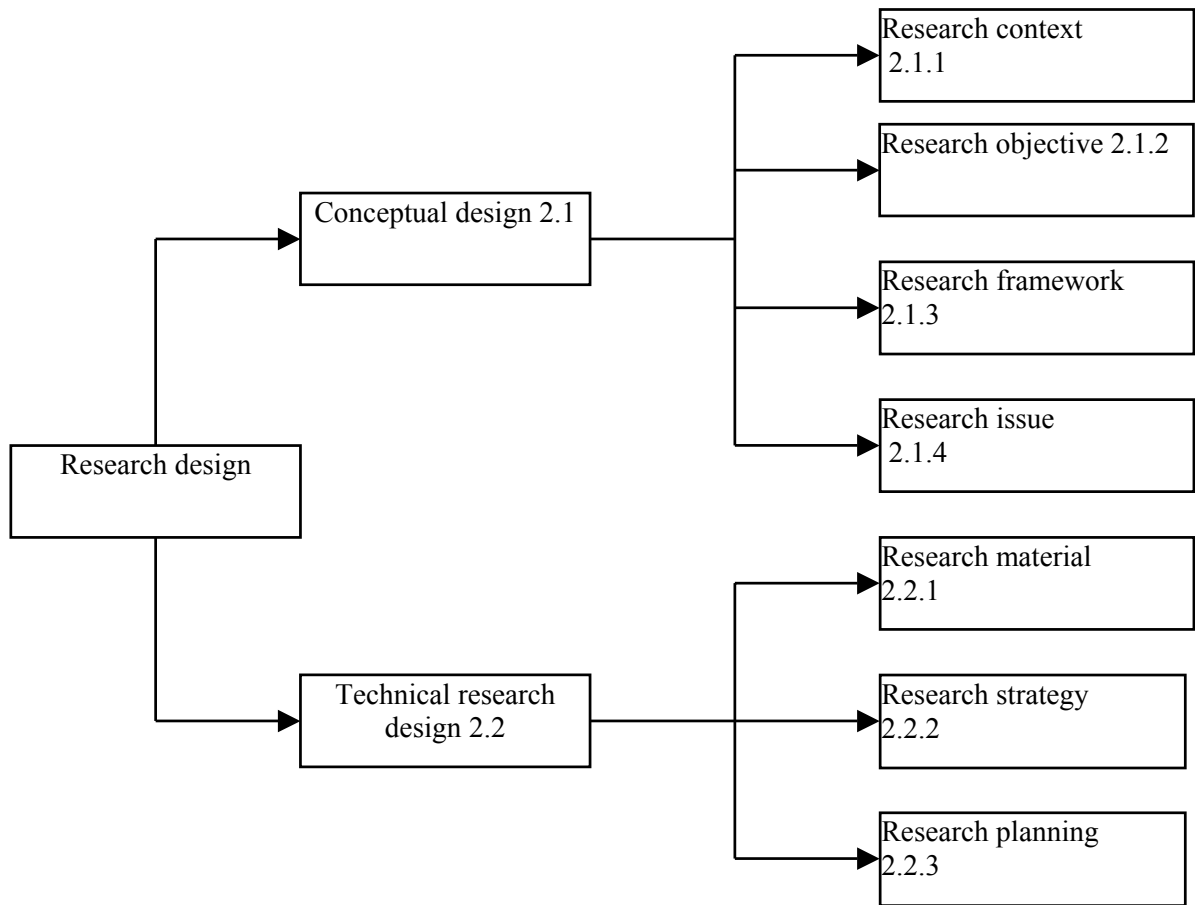


Figure 3.1 Research Design

2.1 Conceptual design

Research projects can be theory-oriented or practice-oriented. Theory-oriented research is about solving a problem encountered in the theory building process.

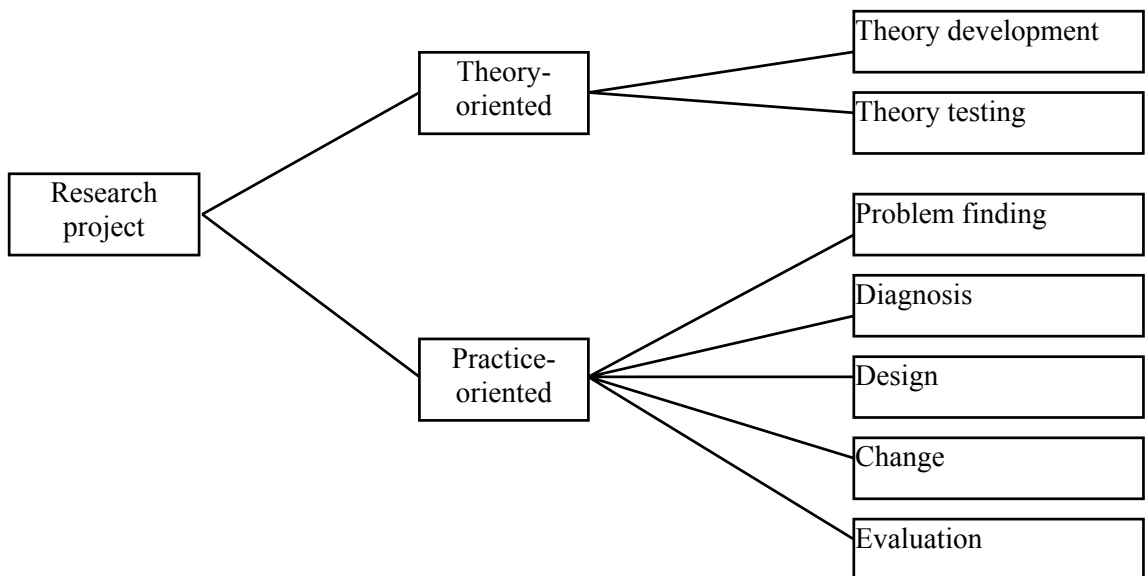


Figure 3.2 Research categories

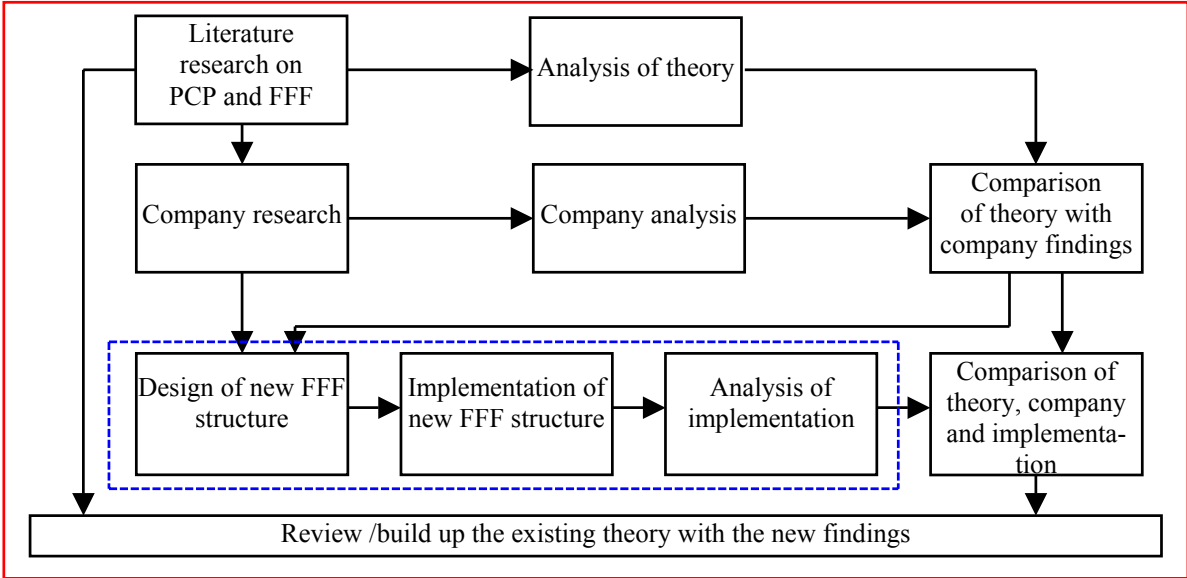
The initial topic of this research was defined as ‘The Development of a Statistical Model for Fast Field Failure Feedback’. It was assumed that collecting, analysing and sending back reliability information from the field to the manufacturer is absolutely necessary if a company wants to check and improve product quality. The reason behind this is that the increasing complexity of current consumer products leads to unpredictable product failure behaviour; therefore the actual performance of a product can only be detected in the field.

It was also assumed that failure / reliability information should reach the company as soon as possible. This is a consequence of the fact that consumer electronics products have a high degree of innovation and, accordingly, the development time of new products becomes shorter and shorter. Under these circumstances up-to-date information about the field performance of previous products is essential in order to prevent reliability problems in a product show up again in its successor.

The available literature on this subject is discussed in the next chapter. In that same chapter it will become clear that, although there is some literature available, the subject has not yet been studied in depth. For this reason a more thorough look at the present situation is necessary in order to find out if reliability field information should be collected. And if the answer is yes, for which purposes and under which conditions this can be done. This leads us to choosing the theory-building approach mentioned in [Ver99], with elements of design-oriented research in a later phase.

[Ver99] categorises design-oriented research as one of the practice-oriented research strategies, but in this thesis it will be shown that this kind of research can be used as part of theory-oriented research as well.

The research steps together with the methodology are visualized in figure 3.3.



Theory-building research ————
Design-oriented research - - - -

Figure 3.3 Research structure

From figure 3.3 it becomes clear that the research strategy of the complete research is theory-oriented, therefore this strategy will be described in more detail in this chapter.

The design-oriented strategy will be explained in chapter 8.

2.1.1 Research context

In the last few decades the quality of products have become very important. In high volume consumer electronics, it is especially difficult to meet the quality and reliability targets. This problem has many aspects: high innovation, short development times, low cost, price erosion, high demands on product and process quality.

2.1.2 Research objective

This research concentrates on product quality/reliability, in particular on collecting field information about product quality/reliability. The objective of this research is to further develop the theory about field failure feedback information flows. This is done by studying the literature and comparing the available theory with several case studies, in order to understand the required field reliability flow from customer to development and manufacturing. To conclude, a new theoretical concept for fast reliability data collection will be developed and tested.

2.1.3 Research framework

In order to get a complete understanding of a theory, one should first study the relevant literature in order to understand the state of the art. For this purpose I studied the literature about product quality/reliability, effectiveness and efficiency, organizational changes and changes of technology.

Subsequently case studies in two companies were performed. One case study concentrated on high-end audio and video products, the other one on audio products in the high-volume market. Each of those case studies concentrated on two aspects: feedback of engineering information and feedback of statistical information from the end user back to the manufacturer. Figure 3.4 gives the conceptual framework.

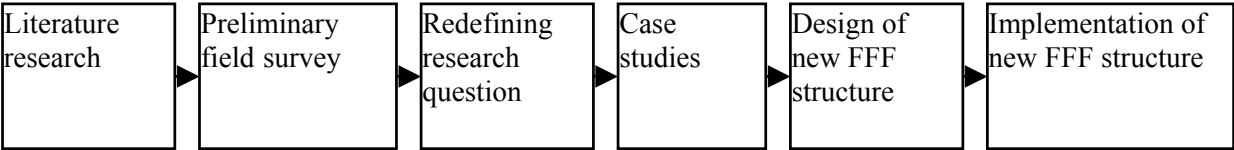


Figure 3.4 Conceptual framework

2.1.4 Research issue

The research issue can be broken down into main research questions and sub-questions. Those questions reflect the information that is useful or necessary in order to realise the research objective.

The research described in this thesis concerns fast PCPs under time to market pressure.

The first central question runs as follows:

What field failures information is vital for product development?

- Sub-questions

Speed- When should the field failures information be available in Development? (Chapters 2 and 6)

Contents- What is the required content of the field failures information? (Chapters 2, 6 and 7)

Analysis- How should the field failures information be analysed? (Chapters 7 and 8)

The second central research question is:

What field failures information do companies collect?

- Sub-questions:

Speed- When is the field failures information available in Development? (Chapters 2 and 6)

Contents- What is the content of the available field failures information? (Chapters 6 and 7)

Analysis- How is the field failures information analysed? (Chapter 6 and 7)

The third research question is:

What activities can be performed to close the gap between needed and available field failures information?

- Sub-questions

Speed- What can be done to improve the speed of field failures information flow? (Chapter 8)

Contents- What can be done to improve the contents of field failures information? (Chapter 8)

Analysis- What can be done to improve the analysis of field failures information? (Chapters 7 8)

2.2 Technical design

2.2.1 Research material

The research uses available literature and materials from industrial partners.

2.2.2 Research strategy

Research methodology literature deals with different methodologies, depending on the research question. A short description of each of them follows. These descriptions aim at showing the advantages of the methodology at issue for dealing with the research questions presented in 2.1.4.

- Experimental studies

The scientific experiments require that the researcher is able to manipulate in some way the independent variables of the research hypothesis, in order to observe the influence of these variables upon the dependant variable under examination.

- Surveys research

In general, a survey involves the collection of information from a large population (e.g. people). It has three characteristics:

- o It involves collecting information by asking people for information in some structured format.
- o Survey research is usually a quantitative method.
- o Information might be gathered via a sample.

- Action research

[Eas91] define action research as an approach, which starts from the view that the role of research is to lead to change, recognising the link between theory and practice.

It is conceivable that action research incorporates some attempt at explanation and solution of particular problem situations, and thus it is often considered within the general heading of applied research. However the distinction is made here to reflect the degree of intervention and partiality of the researcher, which is generally lower in applied research than in action research.

- Case study

Case studies study the problems more in depth. Case studies answer “how” and “why” questions. According to [Yin94] “a “how” or “why” question is being asked about a contemporary set of events over which the investigator has little or no control”.

Table 3.1 gives the requirements and characteristics of each kind of research.

Table 3.1 Summary of the process of research design choice [Cor92])

Research requirements / characteristics	Experimental research	Survey research	Case study	Action research
Presence of the researcher in data collection	Possible	Unusual/difficult	Usual	Usual
Small sample size	Possible	Unusual	Usual	Usual
Variables difficult to quantify	Possible	Possible	Possible	Possible
Perceptive measures	Possible	Possible	Possible	Possible
Confines not pre-defined	Unusual	Difficult	Adequate	Possible
Causality is central	Adequate	Possible	Adequate	Possible
Need to build theory- to answer 'how' question	Possible	Difficult	Adequate	Possible
In depth understanding of decision making process	Difficult	Difficult	Adequate	Possible
Non-active role of researcher	Possible	Possible	Possible	Impossible
Lack of control over variables	Difficult	Possible	Possible	Possible

It can be argued whether the table presented by [Cor92] can be considered 'valid'. For example, in survey research nothing goes wrong if the researcher executes interviews to collect data. The same holds true for small sample sizes; in particular when the researcher wants to collect detailed information, it might be better to concentrate all available forces on a small sample size.

2.2.3 Chosen research strategy

2.2.3.1 Arguments for choosing a case study strategy for industrial aspects

The reasons why a case study strategy is chosen are the following:

- Presence of the researcher in the data collection.

This is essential because this leads to a deeper understanding of the possibilities and limitations.

- Small sample size.

As case studies require an in depth investigation of the actual situation in companies, they take a lot of time. In order to stay within the available time frame, only a few companies can be investigated.

- Provides in depth understanding of the decision making process, which is essential given the research questions.

The confrontation with the actual decision making process brings about that the researcher gets a very good understanding of the possibilities and limitations.

- Better validation.

The better the understanding of the actual situation, the better the research validation.

2.2.3.2 Validation of the case study

The validation of a case study research is vital for theory building research [Yin94]. This research aims to produce universal knowledge. Due to the perceived weakness of a case study design with respect to the possibility to generalise the findings, careful attention has to be given to this aspect (details in Chapter 6). There are limitations, however; action-research does not aspire to the level of law-based generality typical of positivist research (like in natural science), and is more suited to the context-sensitive approach of interpretive research (like in social science), and to inductive low-level theory generation. The validity of research findings is, therefore, strongly based on logical arguments and the provision of generalisable design knowledge [Zwa95] that must be reviewed by experts and interpreted by users in their own situation.

The remainder of this section contains details about the steps to support the scientific value of the case study results in this thesis.

The general applicability of case study based research is based on analytical generalisation rather than statistical generalisation [Yin, 1994] and is primarily influenced by the validity (internal and external) and the repeatability of the results. Each of these aspects are dealt with in turn, including an outline of the strategies pursued in this research to address them:

- Internal validity- refers to the correctness of the causal relations observed within the individual case study. The strategies employed to ensure that no spurious events corrupt the conclusions include the use of:
 - o Multiple units of analysis to provide a broad range of data collection and discussion points to counterbalance any point disturbances.
 - o Well-documented and clearly operationalised case procedures- the assessment method design is detailed and is used as the case study protocol.

- External validity- refers to the domain in which the case studies' findings are applicable. The research domain has been identified as manufacturers of consumer electronics. The following strategy is used to ensure the requisite domain generalisation:
 - o Multiple case studies (with engineering feedback and statistical feedback) are used across separate organisations.
 - o Within each organisation separate departments, individuals and products are used to provide a variety among the cases and so to explore a more representative view on the domain.
- Repeatability (often called reliability)- refers to the repeatability of the results independent of the investigator. It is important to realise that this refers to repeating the research with exactly the same cases but with another investigator, not replicating the research with other cases. The strategy used here is to have a well-documented case procedure; a detailed method design facilitates this and extensive reporting has been done.

3 CONCLUSIONS

The research problem, the research motivation and aim have been presented. The research questions necessary to address the aim have been posed, and the case study based nature of the research has been discussed.

Finally, the overall research design and its relation to the research questions and the subsequent thesis structure have been presented.

Market Trends and their influence on the product quality and reliability information flow

1 INTRODUCTION

In section 2 an overview is presented of the market trends in consumer electronics: increasing product complexity, longer warranty periods, globalisation and segmentation of business processes, time to market, and high innovation. In the same section the influence of those trends on product quality and reliability is discussed. In section 3 the consequences of the market trends are explained: new demands on reliability prediction methods, quality of information, deployment of information in an organisation, time required for obtaining and deploying information. Next the influence of those trends on the product quality and reliability information flow will be given. This gives a good base for starting chapter 5 in which the first research question, as defined in chapter 2, will be discussed.

2 MARKET TRENDS AND THEIR INFLUENCE ON PRODUCT QUALITY AND RELIABILITY

In the following section the main market trends for consumer electronics are described and the influence of these trends on product quality and reliability is discussed.

2.1 Increasing product complexity

During the last few decades, consumer electronics products become increasingly more complex. Much new functionality is included as an attempt of companies to satisfy the customer and to stay or become competitive.

There are four reasons why new functionality is implemented:

- The customer sometimes demands new functionalities, and the way in which the product with these functionalities will be used can be more or less predicted, based on marketing surveys.
- Companies decide to introduce new functionality even when the customer does not show a clear wish of having it. (Deming gives the following reason ‘... the customer is not in a good position to prescribe the product or service that will help him in the future.’ [Dem86]) This can be stimulated by the availability of a new technology, and the fact that the customer cannot imagine that the product could function in a totally new way because of this new functionality.

- A company may decide to bring new functionality on the market just because the competitors already have it, and not including it may cause the loss of customers.
- Price reduction: realising parts of a product in software or digital hardware is cheaper (but far more complex).

As increasing product complexity (i.e. an increase in state space) implies that the interaction between all parts, modules etc. becomes more complex as well, it becomes almost impossible to predict all potential failure mechanisms for a product. (Internal complexity)

No matter who demands/decides on including new functionality in a product the result will be that the customer – product interaction becomes more difficult to predict. (External complexity)

Given the internal and external complexity, it is clear that manufacturers are at high risk when producing innovative products with new functionality. Without an excellent knowledge about the quality of the new products, warranty claims may be much higher than expected. [Bli96]. Poor product quality leads to direct and indirect money loss, for the manufacturer especially during the warranty period, for the customer especially after the warranty period.

2.2 Longer warranty periods

One of the evidences for increased customer demands is the increased length of the warranty periods over the last 10 years. The customer, supported by the law, demands an increase in warranty in coverage as well as in time. More and more companies adopt a ‘no questions asked’ policy. The customer can come back with his/her product within a longer period and ask for repair or replacement without even giving an explanation about the problem he/she has. From this it follows that poor product quality brings more than ever extra costs for the manufacturer.

Table 4.1 Changes in product warrantee in high volume consumer electronics 1989-1999 [Phi89] [Phi99]

	1989	1999
Warranty period	6 months-1year	3 years
Failures covered	Material defects	Any customer complaint

The increase in warranty costs stimulates the interest of manufacturers in improving the product quality. Given the following aspects it cannot be expected that all new products are ‘first time right’:

- Time pressure – in order to stand up to the competition, manufacturers try to be first on the market; this hampers activities like testing, (cf. section 2.4)

- Globalisation – development, suppliers, manufacturing and end user are spread over the globe, what complicates the communication between them, (cf. section 2.3)
- High innovation [Luy99]

This suggests that field failures seem to be inevitable if not enough attention is given to the back end of the product creation process. That means: analyse field failures, find the root cause, and do whatever is necessary to prevent the recurrence of these failures. This view is the starting point of the research project Fast Field Failure Feedback: get direct information from the customer regarding his dissatisfaction about the product (the backend) and use this information to improve the front end.

2.3 Outsourcing and globalisation/segmentation of business processes

As was mentioned in chapter 1, in consumer electronics companies have to be first on the market with products with state of the art functionality, relatively high quality and competitive prices. This forces companies to concentrate on their core-business and to outsource the other activities [Dij97], [Pet00b]. Outsourcing significantly increases the need for co-operation between departments, both internal and external. More and more companies not only outsource parts of production, but also parts of development. Co-operation in development can only be successful if there is a well-structured co-operation process in which everyone is aware of his contribution and everyone has the right information. Given that companies more and more operate on a worldwide scale, this leads to a globalisation and a segmentation of the business processes.

Outsourcing may lead to an unwanted dependency of suppliers. In the short term this concerns the operational risk of not being able to deliver in time. On the long run there is a strategic risk of loss of knowledge and skills at the side of the outsourcer, what makes him totally dependent of the supplier. Another risk connected with outsourcing is related to the completeness of the specifications. Incomplete specifications may have huge consequences for the quality, the delivery time, and the costs.

From the other side, outsourcing can give flexibility: on the short term the supplier might be able to take care of fluctuations in demand; on the long term the outsourcer is less tied to a particular technology because he can choose another supplier when necessary.

As mentioned before, there is a tendency to outsource a lot of activities. This would not be possible if an outsourcer had to co-operate very closely with all of its suppliers. In general an outsourcer will only co-operate very closely with a supplier if there is a serious risk, i.e. a relatively high probability that problems with serious consequences will show up. [Kra83] already mentions these risks in relation to parts that might not be delivered on time, but the same holds true for outsourcing service or development, of course. In relation to figure 4.1 this means that an outsourcer only will co-operate intensively with suppliers when it concerns aspects that are of strategic importance.

Outsourcing means involving more people and more interactions in the business process, which complicates the communication. Outsourcing combined with

globalisation and the increasing uncertainty in many processes multiplies the complications, with all corresponding risks.

2.4 The impact of “time to market”

A complicating factor that is related with the high degree of innovation and the globalisation of the market is the reduction in ‘time to market’ i.e. a reduction of the time from the decision to develop a new product to the market introduction. Every company feels the need to be first on the market. However as it is stated in [Smi98] ‘Speed is not the objective, it is a means to an end; the objective is making money’. As it is shown in figure 4.1 making money means that the right balance has to be found between the relevant factors and the related actions. For example, figure 4.1 suggests that it might be profitable to increase the performance shortfall because this reduces the introduction delay.

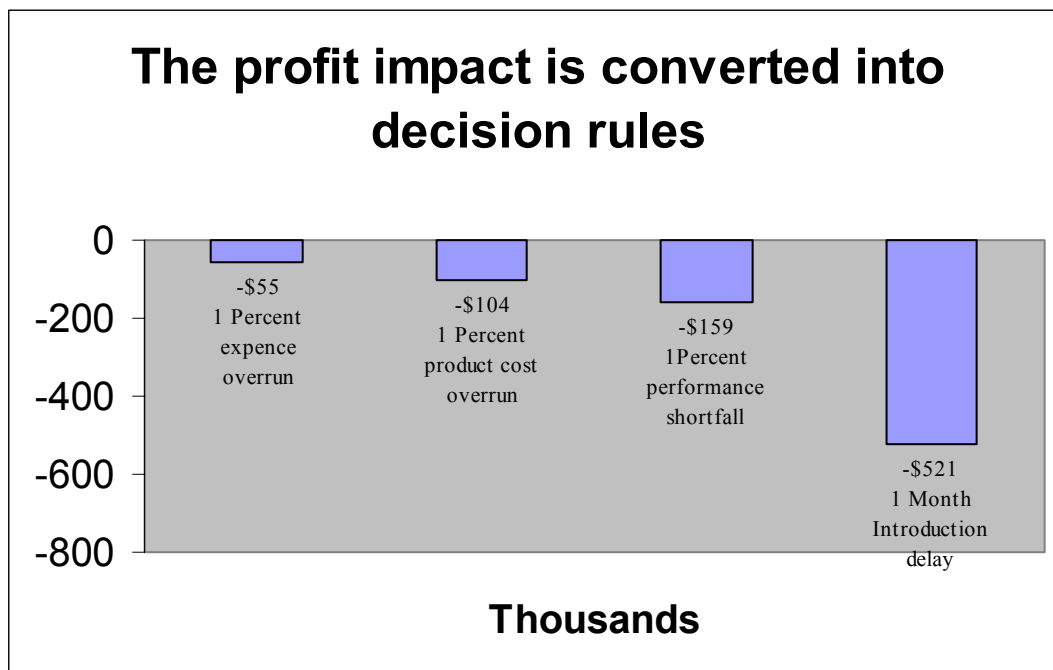


Figure 4.1 The influence of decisions rules on profitability [Smi98]

In the literature the time-to-market dominates product development for high-volume consumer products at this moment. In 1991 in their article “Competing against Time” Stalk and Hout [Sta91] explained the importance of time-to-market. Wheelwright and Clark explained in 1992 in their article Revolutionizing Product Development, the large impact this has on product development [Whe92]. Smith [Smi98] states that from each month cut from a product development cycle, up to a month is added to its sales life. Therefore there is a well-known statement:

- Only who is first on the market might make a profit

Trying to be the first company who puts the product on the market is one of the main goals of companies. In their attempt to be first on the market, companies often skip time consuming activities like testing and overlook (potential) product problems. Obviously, this puts product quality under pressure.

Given the pressure to be first on the market, high volume consumer electronics companies try to shorten their development / product creation cycles. A popular solution is to change their traditional sequential PCP to concurrent engineering. For a better understanding of this transition, the sequential and concurrent engineering PCPs, as well as their advantages and disadvantages in relation to product quality and reliability are described in the next paragraphs.

o Sequential PCP

A traditional product creation process is a sequential phase-gate process that consists of three phases: conception, creation and realisation. According to [Min99] the following number of milestones can punctuate the process:

- Concept start - this is the official start of the project.
- Product range start - launching the creation phase, building and testing of the first functional model.
- Approval functional model - after this a second round of prototypes are build and tested.
- Commitment date - this milestone is passed when technical feasibility and economic viability have been proven.
- Design release - transfer of the product to a manufacturing site.
- Industrial release - start of mass production.
- Commercial release - first shipment to the customer.

Some PCP's have one more phase, namely:

- Pre concept start- Selection of technology, selection of architecture, establishing goals.

A major disadvantage of a sequential phase-gate process is that a new phase can only start when all activities of the previous phase have been completed. This fact automatically suggests a possibility to speed things up:

o Concurrent Engineering PCP

A concurrent engineering product creation process tries to increase the speed of a product creation process by doing activities in parallel.

[Mey97] gives the following reasons for going from a traditional PCP to concurrent engineering. The traditional PCP is:

- Slow and serial - every activity in the traditional PCP starts after the previous activity meets its milestone. This makes the traditional PCP very slow. This prevents the company to be first on the market.

- Concept frozen too early - the concept is frozen after the first milestone.
- Too much focused on gates, not on the customer - the main goal of the participants is to reach the milestone of a phase.

Figure 4.2 demonstrates in a visual and intuitive way the advantage of a concurrent product creation process compared to a phase gate process.

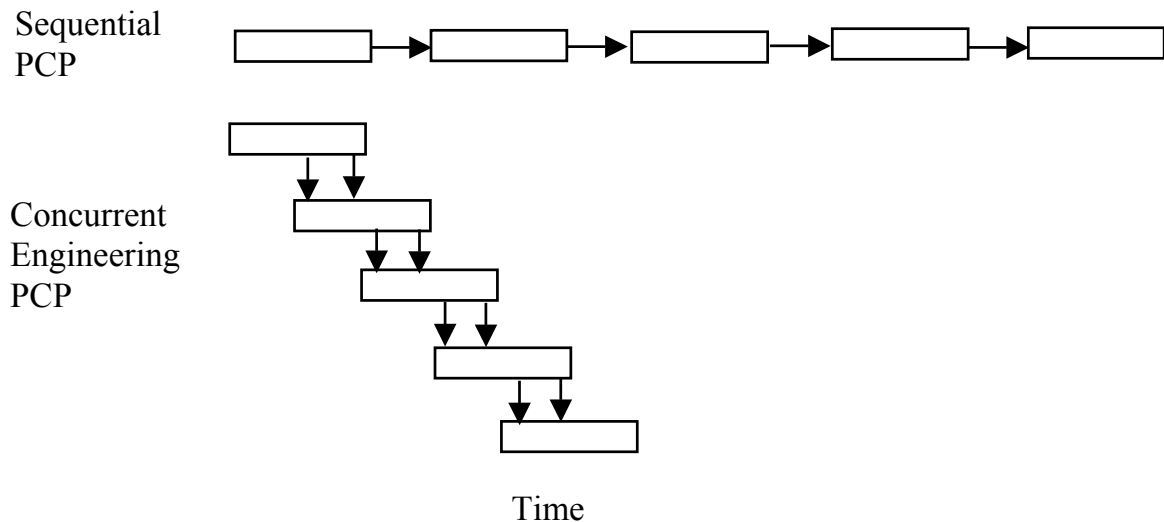


Figure 4.2 Sequential approach versus concurrent engineering

However, everything has its price. In a concurrent product creation process many decisions have to be taken early in the product creation process. This requires that it is possible to foresee all problems that might pop up later in the process. For innovative products – and those are the products we are interested in – this might be unrealistic. Furthermore, early decisions mean that the decision-making is more centralized, and this requires more management attention and higher calibre people. [Smi98]

3 MARKET TRENDS AND THEIR INFLUENCE ON THE INFORMATION FLOW

Some of the recent market trends have a strong influence on the reliability information flow. A discussion on these influences follows in the next sections.

3.1 New demands on reliability prediction methods

The need for reliability prediction methods dates back to at least the Second World War, when the United States Department of Defence formed a special interest group on reliability. The reason for that can be found in [Hen81] and [Eva93], namely that in the last years of the Second World War half of the electronic equipment on naval ships was down due to reliability problems.

During some decades the reliability prediction, at least in the electronic and electrical world seemed a simple procedure, based on exponential failure time distributions for the components of a system. Reliability testing was for several decades almost always based on the assumption of an exponential failure time distribution. This led to the appearance of MIL handbooks and databases. The value of the MIL handbooks has already been discussed in chapter 2 section 2.

Estimating product reliability via an extensive test procedure does not solve the prediction problem either, because the speed of the evolution of new technologies and new product designs and the short lead times between design start and product shipment, in parallel with longer MTTFs and MTBFs, have made it more difficult to find test time to accumulate sufficient failure data to be useful for prediction purposes. Accelerated tests help in reducing the testing time, but they have their disadvantages. For example, it is far from easy to match results from accelerated tests with normal use results. The same holds for failure oriented test procedures. The aim of these is to reach the product limits. However this might not appear in reality.

Everything taken together it seems to make sense to investigate whether it is possible to base reliability predictions on data based on the real usage of the product. Such data can be found in the field. However, as will be shown later, the quality of this data is not always sufficient for reliable prediction. Some aspects of the quality of field data are discussed in the next section. Field information, its potential for predicting quality and reliability of products, and the related problems will be discussed in later chapters.

3.2 *Quality of information*

Prediction of field behaviour requires the right quality of information. This thesis concentrates especially on the relevance of field information and the speed with which this information is fed back to the main PCP.

When speaking about Quality and Reliability of products there are a number of aspects that reduce the quality level of information:

- Information comes in late

As specified earlier, because of the reducing time to market, there is not much time available for detailed root-cause analyses and for implementation of product improvement activities in the product under development. This leads to the possibility that developers are unable to estimate the field behaviour of the product they are working on.

- The available information is not complete enough for quality improvement

The field information collected by companies is mostly for logistic and financial purposes, it is not suitable for finding root causes of reliability problems:

...the types of failure and the causes of failure for electronics have changed over the years...In many cases there are significant numbers of reported failures which are due to “unknown”, “not verified”, and “other” causes, indicating the lack of comprehensive failure analysis or the inability to clearly dissent the cause. In other

cases, failures are attributed to “design”, “testing” and “vendor related” factors without addressing failure causes. [Pec92]

- Information is not fed back to the right place in the product creation process

Very often it is difficult to decide which information should be sent to which department. In many companies there is one person, or a small team that takes those decisions. This is usually the quality management department. Furthermore, decisions are often taken on a common sense basis and there is no structure in which those decisions are taken. Moreover, the people that should receive field information are often not able to specify the type of information they need [Güt99].

- Information is often hidden in a huge amount of data that is difficult to analyse

People who acquire the data do not get feedback about the value of use of the data; this has a negative influence on their motivation [Güt99].

3.3 Time required to obtain and deploy information

Finding the root causes of failures and collecting more useful field information should not be a single means in the pursuit to quality and reliability improvement of products. If this information is not analysed and if the results of the analyses are not reported to the right place in the company, no adequate action can be taken to prevent recurring of failures.

Given the pressure on time to market, and the transition from a classical sequential PCP to concurrent engineering, high volume consumer electronics companies face the need of gathering knowledge about the performance of their product as soon as possible. This knowledge should allow them to improve if not the current product, at least the very next generation.

Brombacher [Bro00] states, based on analysis of several companies in Europe, Asia-Pacific and North America, that it is not uncommon that companies need more than six months to obtain the first field information on actual product quality and reliability.

3.4 Describing information flows

When one discusses information flows, the first step should be to define the goal of the information exchange.

Depending on the goal different kinds of information are relevant. This thesis looks at the information flow from the field to the manufacturer. We split the information in engineering information and statistical information.

Engineering (technical) information is most urgent, because it is used for finding the root causes of field problems. Therefore engineering information should be collected from the very moment that the first customer has a problem with his/her product. Hopefully this information is available even before mass production has started, at least it should be available at such a moment that it is possible to prevent the same problem to occur in the next generation of products.

Statistical information comes in later. Statistical information is necessary for the following reasons:

- To determine the absolute level of defects.
- To find out whether there are modules/components that fail relatively often.
- To assess the lifetime distribution of the time to first failure, which is, for example, relevant for warranty purposes.
- To determine whether the company is learning from the past, for example by checking whether there are differences in product quality over different types of products, or over product generations.

The right way to look at field information is the following:

1. Define the problem one is interested in.
2. Determine what information is necessary and available in order to solve the problem.
3. Check the timeliness of the information.
4. Use the information and solve the problem.

The ways in which information flows are analysed is part of the research within the sub-department PPK where this research is performed, see for example [Ber00], [Bro99], [Luy99], [Mol99], [Pet99] and [San99]. A concept that is often used within PPK for the evaluation of information flows is the Maturity Index for Reliability; a short description of each of the MIR levels follows. For more detailed information about the MIR principle the reader is referred to [Bro98]. In the following sections this concept will be analysed from the point of view of product quality and reliability improvement.

The MIR concept aims at ‘classifying the (quality of-) information flows in an organisation with respect to their ability to measure, understand and improve the quality and reliability of a product in the field’ [Bro98]. The four MIR levels are defined on an ordinal scale:

1. **Quantification** (how much): Quantitative information is available per-product indicating the number of failures in field and production.
2. **Identification** (where): Quantitative information available on primary / secondary failure location:
 - Primary (organisation): Location of the cause of the failure within the Development Process;
 - Secondary (position): Location of the failure within the product (Part NR, Conditions, etc).
3. **Cause** (why): Detailed information is available for all dominant failures on *root-cause* level. This can be translated into *risks* for future products.

4. **Improvement** (what to do): Methods & tools are in place to *anticipate* on reliability risks for future products and *eliminate* these risks where needed.

The MIR concept has proved to be a valuable tool for evaluating information flows. However, it has its weaknesses. These weaknesses are closely related with the translation of the aim of the MIR concept in the MIR levels. I list the following four critical remarks about the MIR principle:

- The definition of the MIR levels lacks consistency. The MIR levels 1, 3 and 4 concern the number of failures, the root causes of the failures, and the elimination of the root causes. These aspects are relevant for all information flows. MIR level 2, however, concerns the location of the cause of the failure. It is not evident that for each and every failure it is possible to locate the cause of the failure before being sure about the root. In case it is easy to determine the location of the cause of the failure (for example the primary root cause is in production because all failures occur in products that are manufactured in the same day/week), then this is useful information for the actual root cause analysis. In short: the MIR levels 1, 3 and 4 are basic levels, while level 2 is an auxiliary level that is only useful in special cases.
- The MIR levels are presented as a hierarchical system on an ordinal scale, but in line with the aim of the MIR concept, the only structure is a classification. For example, the MIR procedure as defined in [BRO98] implies that MIR 3 can only be reached after MIR 1 and MIR 2. However, MIR 1 is about statistical information (see chapter 1 section 3): how much, while MIR 3 is about root causes that means about engineering information. One of the main points of this thesis is that companies should start with root cause analyses immediately after market release, which is long before a serious amount of statistical information is available. So, my recommendation is to start with MIR 3. Of course, one should start with collecting statistical information immediately after product launch, but the statistical information will only be available long after the analyses of the engineering information. My conclusion is that it is better to talk about MIR *aspects* than about MIR *levels*. So, we have three MIR aspects: the statistical aspects, the engineering aspects and the improvement aspects. If one really wants to give an overall MIR score, then a logical metric is the number of MIR aspects that are handled in a satisfying way. However, it is much more informative to give the results for the three MIR aspects separately.
- In case studies not only information flows get a MIR level, but also organisations, see for example [San00]. Apart of my previous point, there is a totally different reason why this is not useful. The MIR concept is about classifying information flows and companies have many information flows, some of them may generate useful statistical information and some (others) may generate useful root cause oriented (engineering) information. It does not make sense to combine conclusions about unrelated information flows (and about unrelated aspects). As the information flows from a product quality point of view concern the PCP and the field feedback, there is some logic in

summarising the conclusions of a MIR analysis on this total area. But that is as far as it goes.

- Last but not least, the MIR approach does not take into account the timeliness of the information. In time-driven development processes not only the information content and deployment is important but also the speed with which the information is gathered and deployed. The usability of information strongly depends on the moment at which the information is available.

In this thesis the MIR principle will not be used. As mentioned before, I concentrate on the two in my view most important information aspects:

- Engineering information: in order to discover the root causes of failures as fast as possible and to improve the product (operational level)
- Statistical information: in order to evaluate the performance of a product in comparison with standards or other products (management level).

4 CONCLUSIONS

This chapter deals with the trends that influence the quality and reliability of products in the current consumer electronics market. The main factors are the following:

- Increasing product complexity
- Longer warranty periods
- Globalisation/ segmentation of business processes
- Reduced ‘time to market’
- Changing customer perspective

In order to assure high quality and reliability of products, companies should anticipate the problems that appear because of these trends. This requires prediction methods that take these trends into account.

It is explained that a correct prediction can only be made when the right information is available, at the right time and at right place.

Field feedback and its use for quality and reliability improvements

1 INTRODUCTION

In the previous chapter the results of a literature survey have been presented. Two aspects were emphasised: first, the market trends that influence the quality and reliability of a product, concentrating on high volume consumer electronics; second, the problems with the current quality and reliability information flows. Altogether the interest in information flow analysis and improvement was clarified.

This chapter explains the necessity of using field feedback information for quality and reliability improvements. Furthermore, it points out the gaps in the available literature regarding field feedback.

The chapter starts with a first description of the quality related activities that companies undertake in response to the recent market trends. An analysis of those activities clarifies the advantages and disadvantages of using each of them for improving the product quality.

Consecutively, the advantages are shown of closing the loop: process-field-process. Finally, the state of the art in this field is presented and the areas in which more work should be done are pointed out, in particular it is pointed out on which aspects this thesis focuses.

2 PRODUCT CREATION PROCESS

In the previous chapter the general structure of a product creation process was discussed. Also the market trends that influence the product creation process were evaluated. It was described that those trends influence the PCP in general, and in particular one of the results of the PCP: the product quality.

The relation between a product creation process and the quality of the end product is further analysed in this section. Examples are presented of activities that are performed in order to produce products with good quality. Consecutively, the gaps in the available literature on field feedback are identified. In the end, the need of fast field feedback structures is identified.

2.1 Problems with the activities that assure high quality of products

2.1.1 Certificates

Companies often consider getting certificates like ISO 9000 as a quality improvement activity within production. However, certificated like ISO 9000 and awards like the Deming, Malcolm Baldrige and EFQM ones, are not a guarantee for excellent product quality / reliability. These problems are quite often caused by a number of reasons [San99]:

- Obtaining quality certificates and awards becomes an independent goal, not connected to actual business operation.
- People have a tendency to focus mainly on nearby customers and forget, especially under pressure, the more remote customers. (Service helps the customer with a complaint, but it does not spend time in searching for the origin of the problem, it does not help two other customers of service, namely design and production).
- Companies are not sticking to the agreed procedure (for example under time pressure).

2.1.2 Tests

Tests are often skipped because of the time pressure that companies experience to put products on the market as soon as possible. In case tests are performed, these are sometimes based on guesses or on a situation that not longer exists. They are mostly oriented towards finding component failures, though there is proof that component failures make up only a minority of all product failures (see figure 2.2).

[Luy00] describes a survey conducted with five high volume consumer electronics manufacturers. This survey revealed that for these five manufacturers there is insufficient information for conducting accelerated reliability testing in their time driven PCPs. It was agreed that the most relevant phases in the four-phase roller coaster failure rate curve of their products, were phase 1 and phase 2 (cf. appendix 1). However, their in-house testing still concentrated on evaluating phase 3 and phase 4. The quality of the information from the field as well as from in house testing certainly dissatisfied the requirements for a good Q&R prediction model.

All this leads to the conclusion that the applied tests cover only a small part of all reliability and quality problems. Thus a new approach should be found.

2.1.3 Q&R predictions

As mentioned in the previous paragraph, there is an urgent need for predictive methods in modern concurrent development processes.

The most often used model on which reliability predictions are based is the so-called bathtub reliability model [Lew96]. This model is characterised by the existence of three phases that the products show with respect to reliability. The first phase is “the infant mortality period” and is characterised by a decreased hazard or failure rate (cf.

appendix 2). This effect is attributed to products containing certain material and/or production flaws. The second phase, the random failure phase, is characterised by a constant failure rate. It is related to the normal use of products. The third phase shows an increasing failure rate and is a consequence of wear-out.

[Won88] presents a four-phase roller-coaster failure rate for electronics systems (see figure 5.1). He mentions that this curve is already presented in [Pec68] and [Jen82]. In this thesis this curve is accepted as a thinking model in the sense that the curve, in particular the indications of hidden 0-hour failures, early wear-out, random failures and systematic wear-out, refer to well-known phenomena that can be seen in reality. These phenomena are much more important than the curve itself. I do not know of any real failure data that produced the four-phase roller-coaster failure rate, but this does not affect the reality of the four types of failure.

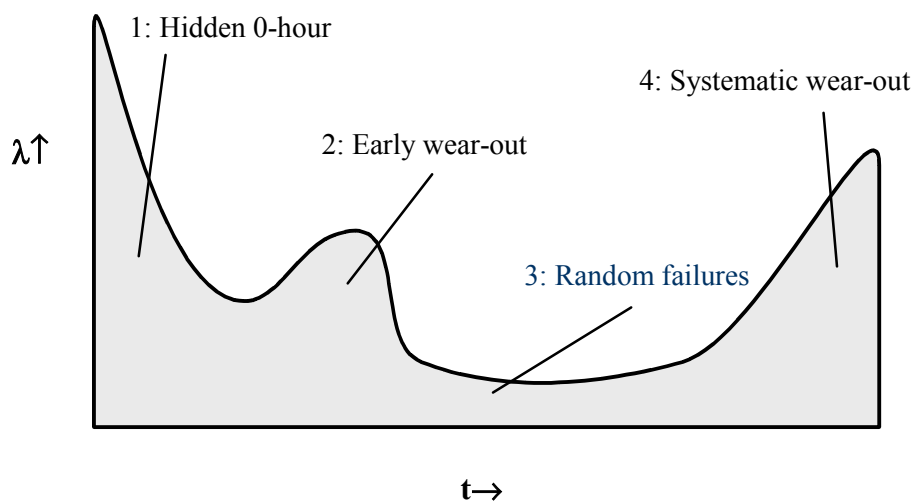


Figure 5.1 Four-phase roller-coaster failure rate curve

In the military industry (the first industry seriously dealing with the prediction of failures) for quite a while the phases 1 and 2 were not given too much attention. The idea was that rigorous test programs would eliminate the flaws. As products in phase 4 were replaced with new ones, one concluded that only phase 3 was of interest for reliability prediction. Since in this phase 3 the failure rate was supposed to be constant, the exponential failure time distribution was used. This line of thinking automatically led to the conclusion that in practice the failure rate of a system equals the sum of the failure rates of the system's components (implicitly assuming independency). [Bro00] states that the bathtub model became so common that many people forget two boundary conditions: the demand that reliability is determined by components only and that the components operate in their useful life phase. I would not be surprised if people do not realise the requirement of independent component failure behaviour either.

The diminishing role of component failures within the total range of failures has already been discussed in some detail in chapter 2 (cf. figure 2.2) and will be discussed again later in this thesis based on data from the companies in which case studies are performed (cf. chapter 6).

Other prediction models can be found in the MIL handbooks. Many authors have questioned the validity of these models for several decades [Sho68]. [Bro92] compares the actual reliability field performance of components in high-volume consumer products with the predictions based on a number of handbooks, and states that there is no relation between the predictions and the actual field behaviour. According to [Bro92], high-volume consumer products never reach the constant failure rate phase, as after a relatively short time (in some cases it can be as short as 6 months) they become economically obsolete and are replaced by newer products.

2.1.4 Product Q&R methods and tools in the PCP

There are a number of Q&R methods and tools that can be used to anticipate the potential product Q&R issues in the PCP. Quality Function Deployment (QFD) [Aka90] is one of them. By translating customer requirements into technical requirements of the product, QFD can help identify the potential product Q&R issues in the early PCP. Failure Mode and Effect Analysis (FMEA) [Jre96] is the other popular approach to anticipate and prevent failures by designing them out of products and processes. As these methods are outside the scope of this research, they will not be further discussed.

In conclusion it can be said that

- During product development there is often insufficient time for rigorous test programs.
- In consumer electronics, given the high volume of products, it is impossible to test each product until it passes the phase of infant mortality (if this exists).
- Given the measures that companies take in order to ketch up with market trends, it is clear that the zero-failures principle is still utopia.
- There is a need for reliability predictions
- Reliability predictions are not very accurate when they are based on the constant failure rate assumption.
- Predictions should be based on field information and should be verified with field data.

3 CLOSING THE LOOP PCP – FIELD: FIELD FEEDBACK

In the previous section the need of collecting the customer experience with the product was identified, and sending back this information to the PCP was found necessary.

Given the situation described earlier, it is unavoidable that customers will be confronted with imperfect products. In order to prevent that the same problems are repeated over and over again in new (generations of) products, it is important to detect and analyse the problems as experienced by the customer as soon as possible. First it has to be detected why the product did not do what the customer expected it to do. The reasons may be:

- The product was not designed to do what the customer expected, but the customer was not aware of this.
- The product was not compatible with the system in which it was used.
- The product was just not good enough; in reliability terminology: the load exceeded the capacity. The root cause may be in the design, in production, in the supplier, or in the material.

Next, this paragraph presents the field feedback concept and the importance of closing the loop from field to business process.

And in the end the literature findings about quality and reliability related field feedback are presented.

3.1 Field Feedback: Deming cycle

In principle a feedback control loop has a simple structure. There is a process and the output of the process has to fulfil certain criteria. In order to check whether the output is in accordance with the specifications, some measurements are done. If these demonstrate that there is a difference between the output and the criteria, then some action is necessary (cf. figure 5.2).

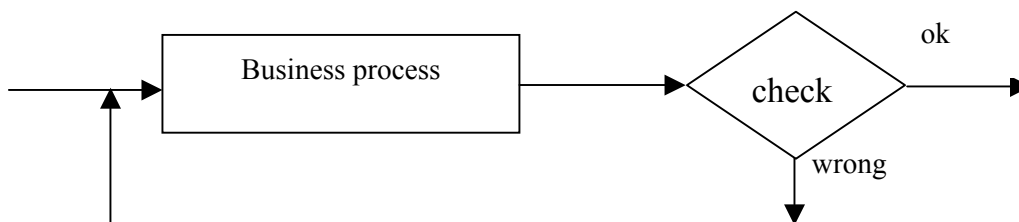


Figure 5.2 Feedback loop

Deming [Lat95] describes very well the disadvantages of an open loop process structure by giving the well-known statement by Henry Ford ‘You can have any colour car you want as long as it is black’. As a result of this attitude there was no

feedback loop from the customer to the manufacturer (Ford), and the competitors that offered choice soon thrived.

Deming presented the closed loop principle by using the so-called Shewhart cycle, later named Deming cycle. Figure 5.3 gives an example.

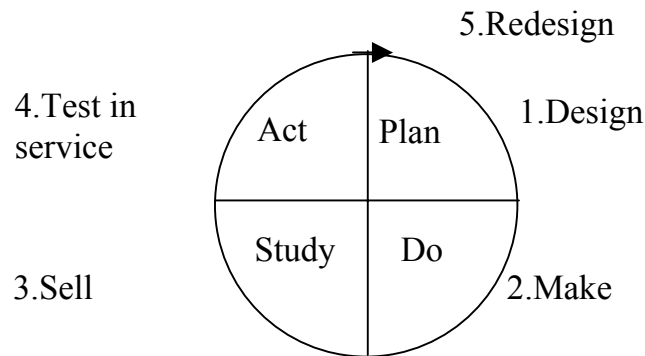


Figure 5.3 The Shewhart/ Deming cycle [Dem86]

In an organisation feedback control loops are necessary on all levels. On a low level they are used in production, examples are automatic control mechanisms and/or statistical process control. On a high level feedback loops have to be used in order to make sure that departments keep in line with the overall company goal.

The most logical way to find what is wrong with the product is to check with the customer. In other words: collect field failure information. The reason is simple:

- It is the only way to find out whether the product does what it should do according to the end user.
- A product is designed for a particular function in well-specified circumstances. As the end user expects a particular function and decides himself about the circumstances in which he will use the product, the designer should be informed about what actually happens in the field.
- Tests are done under well-controlled laboratory conditions; it is not always clear that these laboratory conditions actually reflect the field conditions.
- Even if a product seems to be perfect at final inspection before it leaves the factory, it is not sure that it is still perfect when it arrives at the final customer (after transportation).

The field information that is collected should be targeted at clarifying:

- Whether it is necessary to take the product off the market immediately (e.g. for safety or reliability reasons).
- Whether the reliability is in line with the target, and if not, what has to be changed (root cause) and when.

- What customers expect of the product (e.g. design, functionality, interaction with other products, etc.).
- What the next generation should offer the end user.

All this is enough proof of the statement that manufacturers of high volume consumer products should have a field failure reporting structure. This leads to the next three questions:

- What exactly should be collected?
- Should the information be collected for all products on the market?
- How should the field information be analysed?
- What is the time schedule both for collecting and analysing the field information?

Those questions will be answered later in this thesis (cf. chapter 6 and chapter 7)

3.2 Problems with feedback loop of failures information, according to the available literature

Many authors write about the necessity of collecting useful field information for quality and reliability improvements.

The Reliability Analysis Center [RAC] in its document on Reliability Data Collection Analysis states: ‘in order to adequately address a reliability problem, sufficient data must be available to address thorough analysis’.

[Güt99] puts the emphasis on better analysis and visualisation of field failures data, rather than on collecting new field data. Nevertheless he agrees that there is a strong deficit on failure cause related data and running time related data. The paper reports about the findings of a survey within an industrial project to determine the specific information demand. In the framework of this thesis in particular Guthenke’s following observation is relevant:

- Relevant root cause related information was not available, while at the same time the technicians repairing the products, did not use a big part of the available information.

In practice, often the technicians that repair the products are considered to be incapable of finding the root-cause of failure [Güt99]. My research [Pet99] shows, however, that it is not always right to blame the technicians. At least part of the problem is a consequence of the way service centres are organised, as I now will explain.

Although the voice of the customer has been rediscovered [Dem86], it is certainly not fully integrated in the Product Creation Process (PCP). It is being used more and more in the development phase, but at the other end of the PCP, where the customer comes in as a buyer and user of the products, the customer is hardly ever used as a source of valuable information. There are exceptions, of course, but normally, particularly in the high-volume consumer market, a customer buys a product and as long as the product satisfies their needs, there is no (further) contact between the customer and the

manufacturer. Only when a customer turns to a service centre, is there an exchange of information between the manufacturer and the client. Because of the fact that during the warranty period the manufacturer has to pay the service centre for repairs, there is a pressure to keep the costs of the service centre as low as possible. Consequently, service centres try to reduce the costs by improving logistics and skipping ‘unnecessary’ activities, i.e. activities no one is paying for. This means that a service centre is much more interested in ‘getting rid’ of the client in a limited amount of time, than in trying to find out whether the company can learn from this contact with the customer. Service centres are hardly ever seen as essential elements of the ongoing improvement process and therefore service centres are not assessed according to their contribution to the fundamental solution of reliability problems. At a company level the only information about service centres one is usually interested in, is the total amount of money spent on warranty claims. A typical situation for multinationals is given in figure 5.4. Solely between the service centre and the customer, there is an exchange of reliability related information. The communication between the service centre, the concerning National Sales Organisation (NSO) and the responsible Business Unit (BU) is just about money: who is paying how much to whom to cover the warranty costs, costs of recalls and liability costs. The Service Centre wants to get its money for these services; therefore it contacts the NSO. The NSO in its turn charges the BU. In itself there is nothing wrong with this. What is wrong is, that this is basically the only information that leaves service centres; there is hardly ever an information flow back to Design about field reliability problems. The only information exchange between designers and service centres usually concerns the serviceability of products.

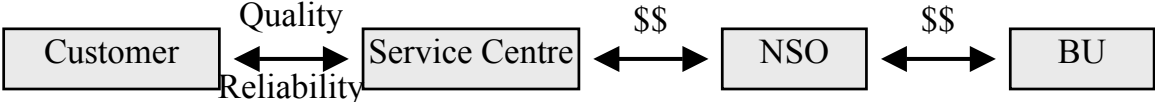


Figure 5.4. Information exchange of Service Centres for repairs under warranty

This leads us to formulation of the first gap:

Gap 1: People that repair the products have no interest in improving the product quality. This has to do with the fact that these people are only paid to repair. Since the service organisations make their money from “unreliability” they are therefore motivated to support unreliability. This subject is beyond the scope of this thesis, thus how to change the situation will not be addressed. This conclusion is only used to motivate the choice of bypassing the repair shops when fast and valuable reliability information should be collected.

3.3 Engineering information

3.3.1 Suitability of field feedback information for finding root causes of field failures

A very strong argument to give just now special attention to engineering field feedback (see definition in chapter 1 section 3) is that at present the problems companies are confronted with are of a different nature than in the past. In the past the reliability of (consumer) products was determined by components. With the increasing reliability of components and the also increasing complexity of the functionality, component related reliability problems have become a minority of current field complaints.

[Pec92] indicates that the types of failures and the causes of failures for electronics have changed over the years.

“In many cases there is a significant number of reported failures which are due to ‘unknown’, ‘not verified’, and ‘other’ causes, indicating the lack of comprehensive failure analysis or the inability to clearly discover the cause. In other cases, failures are attributed to ‘ design’, ‘testing’, and ‘ vendor related’ factors without addressing failure causes”.

Brombacher [Bro96] has quantified this trend and the results were already presented in figure 2.2. According to [Bra99] the situation is even more striking: only 10% of the causes of disasters relate to classical technical reliability problems. This leads to gap 2:

Gap 2: The component related failure information describes only a small part of the current failure mechanisms of consumer electronics products. As service centres only collect component related failure information, the collected information is incomplete. This subject will be further discussed in chapter 6.

3.3.2 Speed of engineering field feedback information

It was mentioned before that companies are under a strong time-to-market pressure. This drives them to very short Product Creation Cycles [Min99]. In the past the PCPs were in the range of a few years. Recently PCPs are shortened to a few months. However, most high volume consumer electronics companies still need at least six months to get usefull field information from a reliability point of view [Bro00].

Table 5.1 Cost per design change in automotive industry (Business Week, April 30, 1990)

Design concept	1000\$
Design engineering	10000\$
Process planning	100000\$
Pilot production	1000000\$
Mass production	10000000\$

This, together with the fact that the cost of design changes increases dramatically in later stages of the PCP (Table 5.1), leads to the conclusion that the speed with which Field Information is collected is of not less importance than the contents of this information. Because of the fact that the length of time of a PCP cycle is currently under pressure – for example during the last few years the PCP cycle of monitors has been reduced from 2 years to 18 weeks – field information must be available as soon as possible (see figure 2.3).

This leads to gap 3:

Gap 3: The speed of the current field feedback information flow does not seem high enough for timely product quality improvements. This subject gets attention in chapters 2, 5 and 6.

3.3.3 Analysis of engineering field information

Prevention of reliability problems depends not only on knowing the root cause of failures, but also on communicating this information within the company with the aim to drive out the root cause. [Bro00] states that failures that happened in approximately 1-2% of the total product population were persistent for at least six product generations.

This all leads to the conclusion that not only the content of field information is important, but also the deployment within the organisation and the speed of this deployment. The analysis of field information gets little serious attention in the literature.

This leads to gap 4:

Gap 4: The analysis of field information is not very well described in the available literature..

This thesis looks separately into the analysis of engineering field failures information (chapter 6) and the analysis of statistical field failures information (chapter 7). The research concentrates on the information flow from the field back to the manufacturer. Processing this information through all relevant departments is beyond the scope of this thesis (cf. [Lu02]).

3.4 Statistical information

As far as the statistical information is concerned, this thesis concentrates on the statistical information that is relevant for monitoring the product performance and for reliability predictions.

[Bla98] states that meaningful quality measures can only be achieved if correlations with field reliability are found, and this can only occur if the user provides failure information feedback. This means that reliability predictions should be based on field information. In the next three paragraphs we look at the literature about: suitability of field feedback for monitoring field behaviour, speed of field feedback information and analysis of field feedback information.

3.4.1 Suitability of field feedback information for monitoring field behaviour

In order to monitor field behaviour we need sufficient data. According to Gutheke “...many companies collect some quality data which they will not incorporate later in their analysis. This, combined with lack of feedback, has a negative influence on the motivation of the people acquiring the data.” [Güt99]

This thesis aims to prove that although a big amount of data is collected within companies, this data is not suitable for monitoring field behaviour.

Gap 5: According to the available literature the field information needed for monitoring the field behavior of a product is available. However, this is not in line with my observations, therefore this assumption will be discussed in chapter 7.

3.4.2 Speed of statistical field feedback information

The speed of the field feedback flow is not widely discussed in the available literature. Brombacher [Bro00] suggests that the field feedback is too slow and can be used for design improvements three generations later.

Gap 6: The speed of the statistical field feedback loop in relation to the PCP has to be investigated. This will be done in chapter 7. In the same chapter the delay caused by the analysis of the available field feedback information will be discussed.

3.4.3 Analysis of statistical field information

The statistical field information can be used to monitor and predict the field behaviour.

The traditional approach to predicting the long-term field reliability of devices, involves implementing statistical models, using the constant failure rate model [Bow92] and [Bow02].

[Mol94] states that analysis and predictions based on constant failure rate assumptions are inadequate, because in general no constant failure rate functions are observed.

Gap 7: The currently available prediction and analysis techniques are mostly based on the constant failure rate assumption, although this assumption is usually not valid. The metrics used in industry to analyse statistical field information will be discussed in chapter 7.

4 CONCLUSIONS

Based on the information given in this chapter some general conclusions can be drawn:

- The literature on field feedback is limited
- Two streams of field information should be separated: engineering information and statistical information
- There is lack of field failure information suitable for quality and reliability improvements

In this chapter seven gaps in the available literature have been mentioned. Not all of these gaps will be discussed in the remainder of this thesis. The following two gaps will not be discussed:

Gap 1: People that repair the products are not interested in improving the product quality. This has to do with the fact that these people are only paid to repair. This subject is beyond the scope of this thesis, thus how to change the situation will not be addressed. As already indicated his conclusion is only used to motivate the choice of bypassing the repair shops when fast and valuable reliability information should be collected.

Gap 4: The analysis of field information is not very well described in the available literature.

The remainder of this thesis concentrates on the following five gaps:

Gap 2: The component related failure information describes only a small part of the current failure mechanisms of consumer electronics products. As service centres only collect component related failure information, the collected information is incomplete. This subject will be further discussed in chapter 6.

Gap 3: The speed of the current field feedback information flow does not seem high enough for timely product quality improvements. This subject is gets attention in the chapters 2, 5 and 6.

Gap 5: According to the available literature the field information needed for monitoring the field behavior of a product is available. However, this is not in line with my observations, therefore this assumption will be discussed in chapter 7.

Gap 6: The speed of the statistical field feedback loop in relation to the PCP has to be investigated. This will be done in chapter 7. In the same chapter the delay caused by the analysis of the available field feedback information will be discussed.

Gap 7: The currently available prediction and analysis techniques are mostly based on the constant failure rate assumption, although this assumption is usually not valid. The metrics used in industry to analyse statistical field information will be discussed in chapter 7.

In the next two chapters cases will be presented that demonstrate what is wrong with the present way of collecting and analysing field information: it is not in time and not well analysed. The case studies are performed at two international manufacturers of consumer electronics.

Chapter 6 presents the above-mentioned aspects looking at the engineering information. And chapter 7 discusses the same matters concentrating on the statistical field failure information.

The information presented in both chapters will be compared with the information in the current chapter, and the new findings will be used to upgrade the theory about field failure feedback.

Field Feedback of Engineering Quality and Reliability Related Information

1 INTRODUCTION

In the previous chapter the necessity of using and improving the field feedback loop was explained. This was done on the basis of the available literature. It was identified that usually companies collect much less field failure information than demanded for a root-cause analysis and that the field feedback information flow is very slow compared with the new product development process, in particular field feedback is too slow for improving the current generation of products. This phenomenon can be explained by the fact that companies concentrate on the logistical aspects, like repair parts management, and on (warranty) costs. For these aspects the time pressure is much less relevant.

This chapter presents two cases performed in two international consumer electronics companies. First the information flow from field to manufacturer is evaluated on speed and level of detail for root-cause analyses. Consecutively the reasons behind time and information losses in the information flow are brought to light. The focus is on the engineering information from the field i.e. the information that should indicate the failure mechanism of a product. It is made clear why companies should concentrate on engineering information immediately from the appearance of the first field failure, instead of waiting for statistical information indicating endemic failures.

The objective is to answer the first two research questions (cf. chapter 3). For this reason two different companies are chosen. The first company is a so-called high-end consumer electronics company, and the second one is a high volume consumer electronics company. In section 2 the choice of these companies is explained by looking at the methodology related to case studies research. The two cases are presented in the sections 2 and 3. The differences between the information flows as well as the similarities are presented in section 4.

2 CASE HIGH-END

2.1 Company introduction

High-End is a small size company that develops, manufactures and sells high-end audio and video products for the consumer market. Basically every year a new product concept or a next generation of products is launched.

High-End exports 76% of its production, and this percentage is increasing. Two new markets with a strong growth potential are the USA and Asia. During the last few years High-End's distribution strategy concentrates on the opening of dedicated High-End shops.

Recently, High-End has set up an internet-based retail system in which all dealers and service centres are linked to the corporate headquarter. This system not only means administrative efficiency in connection with on-line order processing, but it will also result in a far closer dialogue between the individual shops and High-End. This also provides better opportunities to service customers. The system not only entails faster order processing, but in the long term High-End will be able to keep dealers fully informed about new products, marketing initiatives and general developments. With regard to field information, a similar or more elaborate structure of the retail system can provide High-End with field feedback. A special program for Selected Dealers (see section 2.2.1) and a Customer Satisfaction Index (measuring the satisfaction of the customer regarding repairs) are already available.

One of the main objectives of the company is to satisfy its customers. This can be achieved by offering the customer a product with the quality that the customer expects. This by itself necessitates the need to know the actual performance of the products on the market and, in case of product problems, to find the root cause of those problems.

2.2 Field feedback information flow

The products of High-End are highly innovative products. The company does not use standard designs and every product is unique. The development of these products takes a relatively long time, what did not use to be a problem. However, also in this market segment the competition increase, which puts pressure on the time-to-market. The company realises that in these circumstances getting fast field feedback is very important.

2.2.1 Overview

The case study described in the following sections was done by means of personal visits over a period of two years. The author did part of the research personally; another part was performed by a Masters student Industrial Engineering and Management Science, in the framework of his final year project. This student was situated at High-End and closely supervised by the author. The author has visited High-End on a regular basis, about three or four days every three months, and between those visits people from the company visited the TU/e. Videoconferences with the student involved in the research were done weekly. High-End's departmental Quality Manager usually attended these videoconferences. Besides the Quality Manager, managers and employees of the following departments have been involved in the case study:

- Marketing
- Design and Development
- Electrical and Mechanical Engineering

- Purchasing
- Assembly
- Sales
- Service

Based on all interviews and the research performed by the student figure 6.1 was drawn. This figure illustrates the feedback information flow of High-End. It shows that there are three departments involved in the feedback process from the customer experiencing a problem, back to the manufacturer, more specific, to the quality department.

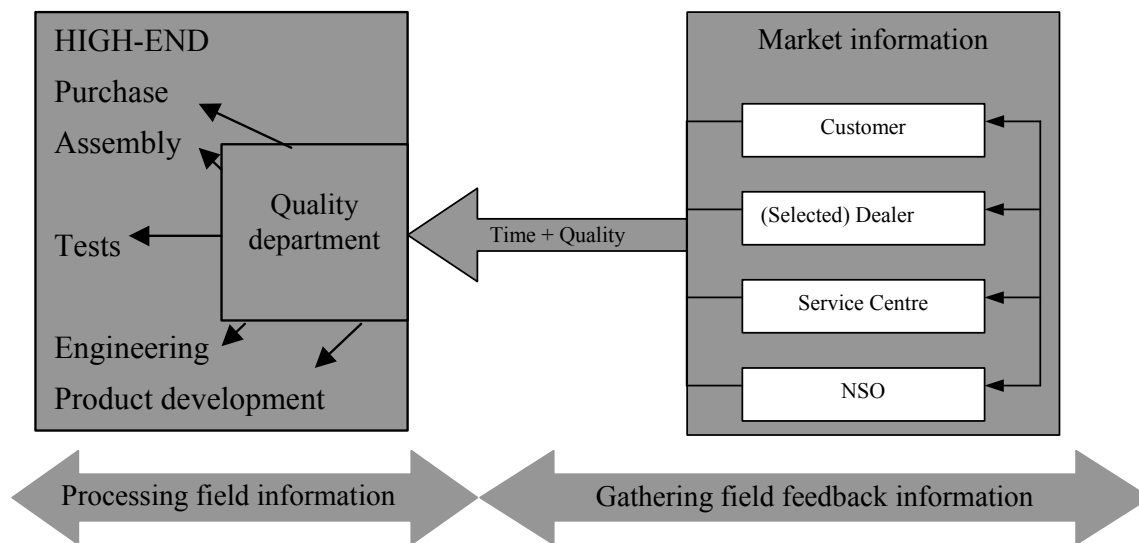


Figure 6.1 Feedback information flow of High-End, focussing on time and quality aspects of the information flow

In the following, first the role of every department is described. Next, the contribution of the information coming from some of these departments to the root-cause analysis will be discussed (section 2.2.2). Finally, the speed of the field feedback flow (section 2.2.3) will be described.

- Customer

The direct contact between customers and High-End is performed through the so-called Customer Contact Centre (CCC). The customers turn to the CCC using e-mails, faxes, letters and phone calls. The major part of the contacts (95%) is in the form of e-mail, and this percentage is expected to increase in the future.

Customers contact the CCC when they have a question. These questions are categorised in a number of groups: product commercial, product technical, documentation, direct purchase, praise and miscellaneous.

The target for the response time of the CCC is the following: one day for e-mails, within two days for faxes, within 5 working days for letters, and immediately, of course, for phone calls.

However, the time elapsed between the moment that a customer realises that he has a question or problem, and the moment that the contact is realised, is difficult to estimate. No statistics are available about this, because the first priority of the CCC is servicing the customer when the contact has been made. How much time elapsed before the contact was made is not important from the point of view of the CCC, however, it is important with regard to *fast* field feedback.

The categories of the contacts are for a major part not product related (figure 6.2). From the point of view of this thesis, only the technical product related contacts are relevant.

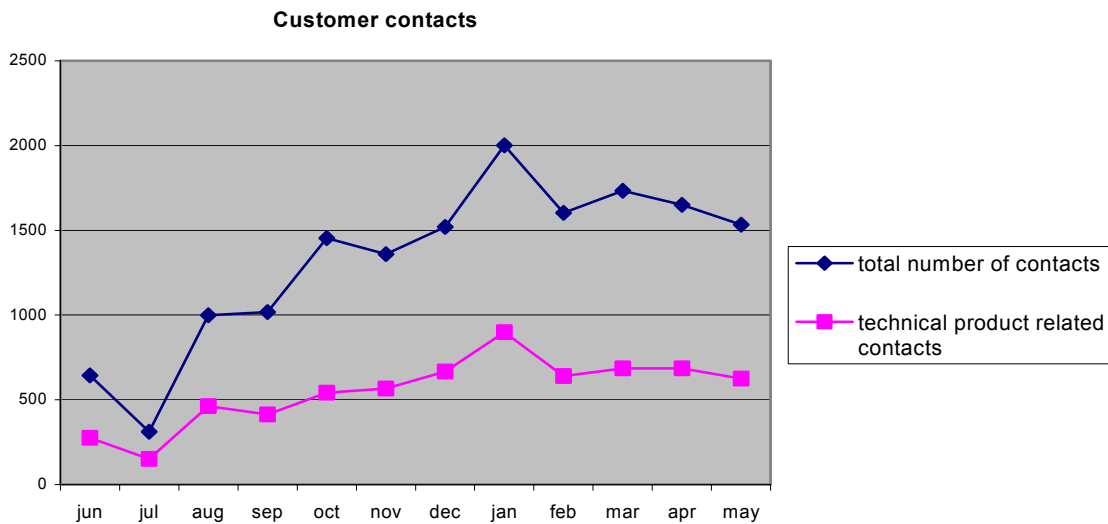


Figure 6. 2 Total number of CCC contacts and technical product related contacts for a new product in 2001

The technical product related information that is collected by the CCC is about: installation, operation, accessories, compatibility, repair assistance, spare parts, modification, and specification. Unfortunately, most of the information is collected via e-mail in a free text form. From the analysis of the information and interviews with people from the Quality Department (QD) it was concluded by the author and agreed with QD that it is not suitable for root cause analyses.

- (Selected) dealer

Part of the company policy is to pay special attention to every single customer. The consequence is that the dealer becomes the main interface between the customer and the company when a product failure occurs. The reasons behind it are the following: the short distance between dealer and customer; the possibility for the dealer to visit

the customer; and the possibility of a fast reaction, because some of the dealers have their own repair centre and then the customer can be helped within a few hours.

However, when the dealer is not able to solve the problem, he contacts the company; there is no direct contact between customer and specialist in the company. This situation usually arrives in relation with the already mentioned Fault Not Found failures, that is when the customer experiences a failure and the failure is not reproducible in service. An important observation is that the only person that really has seen the failure, the customer, is left out of the communication loop.

Two years ago the company started a program involving part of the most trusted dealers, with the aim to get direct knowledge of the most important field. It is an additional way to get fast field information and it is not a substitute for normal communications and business routines. The program was started focussing on quality related issues and lately expanded with issues like ordering, logistics, transportation etc.

The company expectations with regard to solving quality related issues is very high for this program, therefore the information from the Selected Dealers is evaluated in sections 2.2.2 and 2.2.3. Special attention is given to the speed with which the cases are sent back to the company and the suitability of this information for solving quality issues.

The information from the rest of the dealers will be discussed in the next paragraph, but only for the dealers with a repair centre. This is to concentrate on information that is initially intended to serve quality issues.

- Service Centre

High-End has two kinds of repair centres- centralised ones and repair centres at the dealers place. A repair action is initiated when the problem cannot be solved during a visit to the customer's home.

In order to get a warranty claim approved and to be paid back by the company the dealer or the centralised service centre has to fill in the IRIS (International Repair Information System) repair codes (cf. Appendix 2).

- The symptom area describes the set's malfunction as perceived by the user. It requires no specific technical know-how to be filled in, and it uses a *condition* and a *symptom code*. Because of the high innovation degree, these codes do not always cover all product failures, even though the IRIS codes are updated every few years.
- The diagnosis area is intended for the technician to describe where the fault was located, and the actions that were taken by him to repair the product. It uses the *section code*, *part references*, *defect codes*, *repair codes* and a *repair flag* [AEC00]

Most of the claims cover the failures during the warranty period, and a very small part covers after warranty problems. The after warranty repair data is available mostly in

case the failure can have a big impact on the gap between customer expectations and customer perceptions.

Before reaching the company, the IRIS codes data undergo some checks. The first one is performed by the National Sales Organisations. They decide if all the necessary information is filled in and if the repair centre/dealer has to be paid for that specific repair. The claim is further send to the company where the information is checked on more detailed level by the service consultant and the technical product manager. The invalid data is removed, and the rest is stored in a database for further analysis.

The IRIS code database was initially intended to serve quality purposes, i.e. it was intended to help the company to find and solve field problems and/or prevent the reoccurring of those problems in other products. For this reason this database will be evaluated later in this chapter. The criteria for evaluation are the same as for the data from the Selected Dealers mentioned in the previous paragraph.

- NSO

The structure of the National Sales Organisations (NSO) in the different countries has specific characteristics and includes the dealers with and without repair centres, repair centres (no sales, only repair), centralised repair centres and competence centres.

A NSO is responsible for the distribution of products in a country, and it is also responsible for approving subsidiary decisions in case of warranty claims (i.e. IRIS data codes validation).

NSOs are not responsible for root-cause analyses and product quality improvement. For those reasons the NSOs are left outside the scope of this research.

2.2.2 Usability for finding root-causes

Product quality improvement requires a Root Cause Analysis (RCA) for failed products. From the previous section it follows that the CCC and the NSOs are not in a position to contribute to an RCA. In this section the role of the other players is discussed.

- Repair centre information (IRIS code) and RCA

The repair coding gives a detailed description of the customer's complaint. The symptom area gives the product's malfunction as perceived by the customer and the diagnosis area is intended for the technician to describe where the defect was located, and the actions that were taken to repair the product.

When the product is repaired in the customer's home and the replaced module is going to Module Repair in the Quality Department, the IRIS codes are not used, because the symptom codes provide only a rough indication of the problem and the diagnosis codes only gives the specific information that the module has been replaced.

When the product is not repaired at the customer's home but in a repair centre, the symptom and condition codes provide the customer's experience and the location of the failure within the product. However, there has been a loss of information, namely the customer's set-up, which can influence the product behaviour.

The NSO, the service consultant filters the data; in particular, they delete the invalid data for calculating the Call Rate and the TOP lists of most frequent failures. The Call Rate, however, only has statistical and budgetary purposes; while the TOP lists also provides priorities for improvement issues. The Call Rate and TOP lists do not have any value for a root cause analysis.

The repair data of High-End consists of guarantee and fairness repairs (see figure 6.3). The guarantee repairs provide High-End with information about the first 2 years use of the products by the customer. In addition, the fairness repairs provide information about the products in a later stage of the Product Life Cycle. This is important because organizations are responsible for their products during the whole Product Life Cycle, including the wear-out stage. Nowadays the only information about the wear-out stage is from the demand of spare parts.

Dealers are obliged to fill in the IRIS coding in order to get their claims approved. So, even when the complete reason for the complaint and circumstances under which it showed up are not known, some IRIS codes will be filled in. And this has repercussions on the validity/reliability of the information and consequently on the Root Cause Analysis.

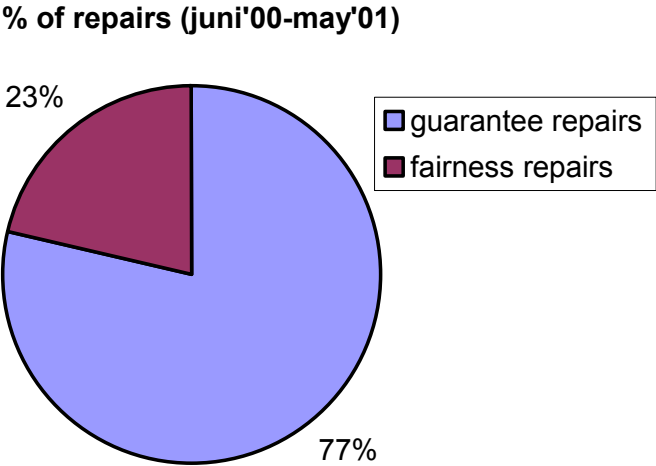


Figure 6. 3 Division of guarantee and fairness repairs in last financial year

The modules get an account number when entering Module Repair and the original IRIS codes are not linked to the module, so the use of IRIS codes for the RCA is impossible. The possibility to use the IRIS repair data in Module Repair for a RCA is limited anyway because (1) the information of the customer set-up and (2) the interaction of the module within the original product have already been lost. And in addition (3) the location of the failure, the symptom, is not necessarily the location of the root cause.

Product behaviour is also influenced by the customer's set-up, but, again, this information is lost. Furthermore, product failures that are submitted to Product Repair could not be repaired in the customer's home, so no information is available on root cause level. Although the repair department uses the IRIS codes to locate the failure, IRIS is not structurally used for a RCA (and for finding all the dominant failures).

The IRIS (guarantee and fairness) repairs are used for calculating the Call Rate; this is only for statistical and financial purposes and has no value for an RCA. The Call Rate shows the "learning curve" of running products compared to the goal of 10 % product quality improvement every year (and this information is only available after a year). The accepted IRIS repairs (total minus invalid) are used for calculating the TOP lists of most frequent failures. This list facilitates the prioritising of quality improvement actions, but it does not provide information for RCA.

- Feedback from the Selected Dealers mainly and RCA

The feedback by the Selected Dealers describes the customer experience about product-related subjects. The information is mainly not technical repair feedback, but basically rather 'soft' feedback about complaints. This facilitates early symptom recognition for High-End, but the information is not useful for a Root Cause Analysis. The information, however, could indicate a serious problem in the field and the failed product or module can be sent to the headquarters to investigate the fault and to perform a root cause analysis. In this way gets an early warning about new failure symptoms.

Part of the information is useful for a location analysis: which organizational part in the business processes is responsible for the failure (primary location), and what is the position of the fault within the product (the secondary location). The information facilitates a first analysis to start an RCA, but testing the returned product is necessary to find the root cause.

The information is not structurally used for RCAs because it is not suitable for it. For example, often the serial number is not provided, which implies that the age of the product is not known, and neither are the components, hard- and software versions. This seriously complicates a detailed root cause analysis. Some kind of incentive for the Selected Dealers to provide all relevant information could partially solve this problem of incomplete information.

The feedback is product-related information about special focus areas, customer complaints and customer disappointments. It is possible (but not common practice) that High-End requests for information about special areas of interest; for example recently launched products or issues where problems are expected. The possibility to ask for special areas of interest and clarifying questions facilitates an RCA. Customer behaviour or other circumstances can provide the necessary information to clarify the cause of a failure.

2.2.3 Speed

Getting field information is essential in order to learn from problems and improve the fitness for use. But to facilitate fast anticipation of field problems, the information has to be available in time. In this section the time aspects of the different sources of field information are described. The analysis is performed with respect to the target: To speed up the flow of field feedback when it is useful, meaning that it makes only sense to speed up the gathering of field information if this information can be, and is, used immediately.

The analysis has to answer some questions regarding time aspects of the field feedback:

- Is the field feedback fast enough considering adequate and timely redesign on running products?
- Is it fast enough to make changes to new launched products to minimize the consequences (customer satisfaction, market position, financial?)
- Is it fast enough to learn from and to anticipate on quality and reliability risks in subsequent product generations?

This paragraph describes the Selected Dealer information database and the IRIS code information databases. First facts and figures on the speed with which this information is available are presented. Later the usability of this information for quality improvements in running products given the speed of feedback information flow is analysed.

- Repair centre information (IRIS code) and time

The field information from the repair centre comes in the form of IRIS code (cf. Appendix 3).

The target is to have 80% of the repair data available within 2 weeks and 100% within 4 weeks after the repair took place. In general, this is not achieved, however there is an improvement compared to last financial year (figure 6.4).

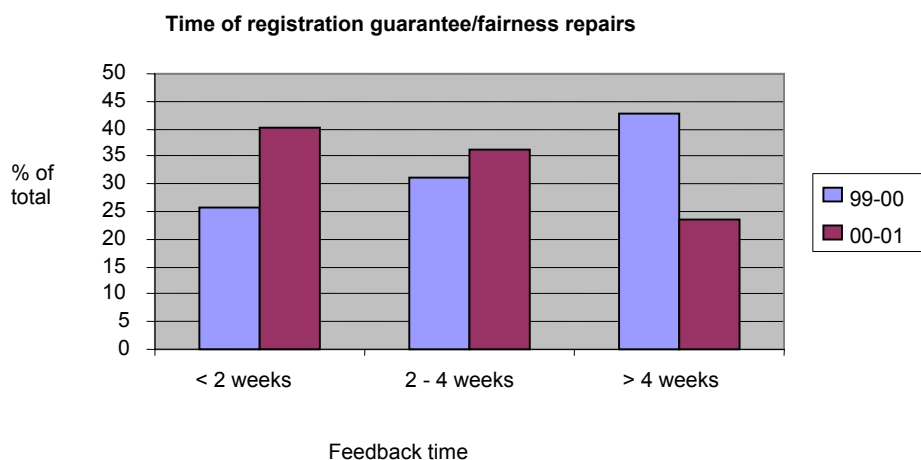


Figure 6.4 Availability of IRIS data in weeks

It might be interesting to see whether there is a relation between the delay in reporting and the type of defect thought to exist, but this has not been investigated.

The elapse of time between the repair and the submitting of the IRIS codes varies much from country to countries (figure 6.5). Different distribution structures and the availability of responsible persons are the most important causes of this time difference.

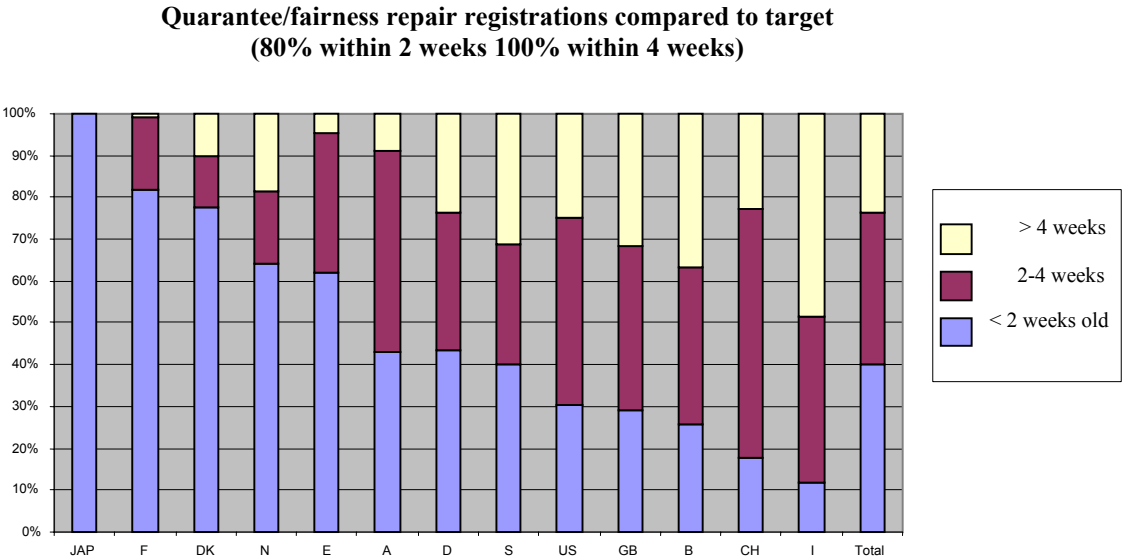


Figure 6.5 Availability of IRIS data by country in weeks

The information is fast enough (when according to target) for redesign of running products; however the ideal situation would be that each product failure that requires a change in a product or a process, is known at High-End immediately. When a product has been repaired, the flow of the IRIS data needs time to be processed in the different channels, like the repair centre, the NSOs and High-End.

Every production day of products with a fault costs a considerable amount of money. If the product is already out of production when field failure information becomes available, a service solution (e.g. a software update) needs to be searched for.

Product launches that are based on a completely new technology or architecture demand a close follow-up where they are launched, to anticipate unforeseen quality and reliability risks. A product launch is normally first tried out on a specific market, but the IRIS data is not fast enough to provide quantitative and qualitative information about the market experiences. In this case testing of each problem that occurs is a more valuable source of information.

So additional field feedback is necessary besides the repair data, e.g. information from the Selected Dealers, because this provides a fast symptom description of the product behaviour in the market.

- Selected Dealer's information and time

The intention is that the Selected Dealers (SD) send their cases on a daily basis, every time a customer has a disappointing quality experience. The primary purpose of the individual dealers, however, is their turnover. A common way is to send the cases to the headquarter in batches, resulting in a delay of up to one week. So, the Selected Dealers provides the service department with a fast feedback of customer cases within a week after the contact with the customer has been taken place.

A selected group of dealers from all over the world provides the cases. Together they send an average number of 250 cases a month (figure 6.6), with a negative deviation in the summer holidays and the Christmas rush, and a positive deviation directly after that.

The different dealers show considerable differences in the number of cases they send; the reason seems to be that some dealers are just more conscientious in sending all quality related cases, or they recognize the importance of the selected dealers program for High-End (and for the dealers).

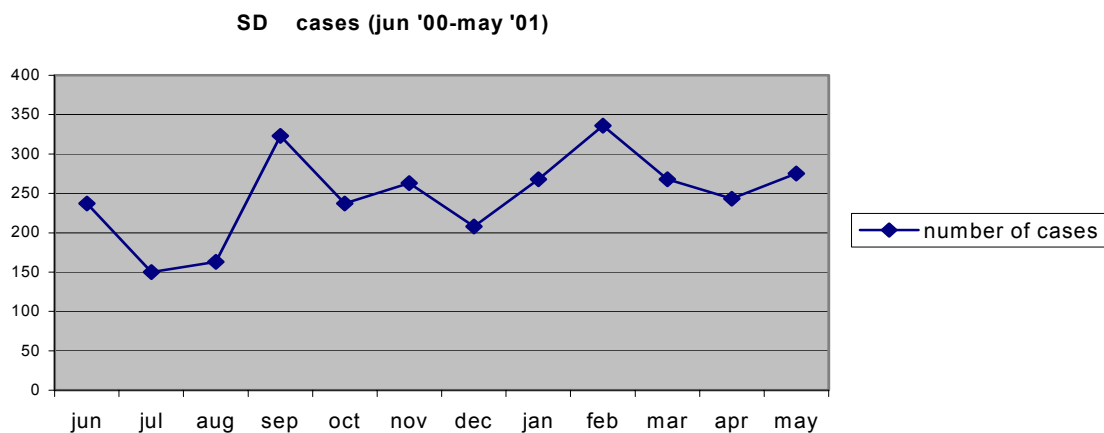


Figure 6.6 Number of SD cases in the financial year 2000-2001

The graph shows a decline of cases in the busy periods of the year and more cases after these periods. It is obvious that (part of) the cases occurred already in these busy periods but were sent just after that. This is not a major problem when the dealers send the most important (time critical) cases immediately and the less time critical cases after the busy period, however, this requires that the dealer is capable of judging how time critical the cases are. Fortunately the selected dealers seem to be quite capable.

The selected dealer cases provide fast SYMPTOM descriptions in order to facilitate a fast anticipation of (new) problems in the market. It is used to inform High-End of a problem, and additional testing of the returned product is necessary to find the root cause.

The common way of working, however, shows that the cases are sent in a sort of batch, this can result in a delay up till a week. If the delay is not getting longer this is a minor problem issue, also because the dealers are pretty capable of judging how urgent problems are and they send these time-critical cases immediately.

2.3 Conclusions Case High-End

From the information provided in section 2, the following conclusions can be made:

- Only the repair centres and the selected dealers are capable to deliver reliability related field feedback information.
- The field information from the Service Centres comes within four weeks after product introduction. Every production day of products with a fault costs a considerable amount of money. If the product is already out of production when field failure information becomes available, a service solution (e.g. software update) needs to be searched for. The information from service centres comes in the form of IRIS code, that might be unclear and not giving any indication about the root cause of the failure.
- The field information from the Selected Dealers program provides information faster than the service centres. However, this information is on symptom level, and does not give a clear indication of the root cause of a failure.
- There is no direct contact between the customer who experiences the problem and the High-End experts.

The field information has some potential that is useful in performing a root cause analysis, however this potential is hardly ever utilized. The presently performed RCAs use field information only for categorizing and deciding which product problems need to be analysed. The Selected Dealers provide such symptom failure information.

In general the field information is not detailed enough (only symptom description), valid (the filled in IRIS codes cannot be trusted) or complete enough (missing technical- or customer specific information, such as serial number or customers' set-up) for a root cause analysis. The field information has to be improved in quantity as well as in quality to facilitate an RCA. Information about field failures should be a combination of symptom related information, repair actions and customer use/environment. Because the potential for improving the existing field information is limited, the focus is at finding additional ways of fast field feedback that is suitable for an RCA.

3 CASE HIGH-VOLUME

3.1 Company introduction

High-Volume is one of the biggest electronic manufacturers in the World. It produces a wide range of products for a wide range of customers in big volumes.

High-Volume has divisions all over the World that makes the communication between and the exchange of information between them rather difficult. In order to make the analysis of the field feedback structure and the field feedback itself manageable, one division was chosen and the field feedback flow for this division was thoroughly examined. From internal documents and interviews it can be concluded that the way in which the field feedback is structured is similar in all the units within High-Volume.

One of the streams within the company is consumer electronics. This case study is performed in one of the consumer electronics unit, namely the audio/ video unit. When we write High-Volume, we refer to this unit.

3.2 Field feedback information flow

It is High-Volumes opinion that taking giant technical steps in a product realisation project makes these projects risky, complex and expensive. In contrast, innovating with smaller technical steps should be safer, should cost less and trim development time. At the same time, this procedure should make it easier to adapt fast to changing market requirements should facilitates to experiment in the market. Taking smaller steps means smaller PCP cycles with less new design content. High-Volume hopes to achieve this situation by:

- Changing less (leaving more of previous design untouched).
- Using (global) standard designs, that are developed in separate projects, and/or
- Contracting suppliers to do (part of) the development work, separate from the development project.

3.2.1 Overview

The case study described in the following sections was done by mean of personal visits over a period of two years. The author did part of the research personally, another part was performed by three student closely supervised by the author. The author has visited High-Volume on a regular basis, about two or three days every three months, and people from the company has visited TU/e regularly as well. High-End's Departmental Manager Quality attended most meetings.

The activities in this case study were concentrated on getting relevant field data to the Quality Department, and were performed to a great extend by the students involved in this research.

Besides the Quality Manager, managers and employees of the following departments have been involved in the case study:

- Design and Development
- Engineering
- Testing
- Assembly
- Service

Based on the discussions figure 6.7 was drawn. This figure presents the departments involved in field feedback process. The figure is similar to figure 6.1.

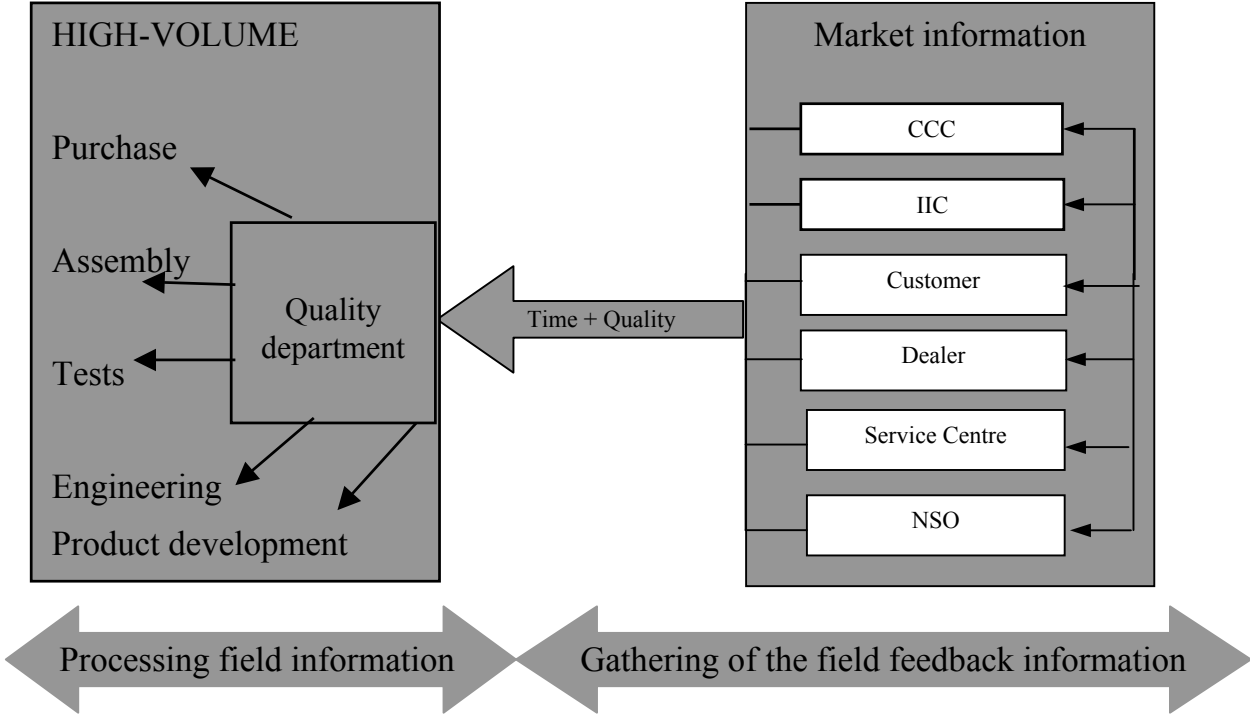


Figure 6.7 Feedback information flow of High-Volume, focussing on time and quality aspects of the information flow

In the following paragraphs each of the departments involved in the collection of field information is described. Next, the usability of the information that those departments generate is discussed (section 3.2.2). Finally, the speed of this field feedback information is examined (section 3.2.3)

- Customer Contact Centre (CCC)

A Customer Contact Centre (CCC) is an interface responsible for solving customer's problems by phone (fax/e-mail). CCCs task regarding the field failure feedback is to filter the soft failures from the hard ones. In this way the CCC reduces the number of products that end in a service centre.

CCC is contacted by the customers as well as by dealers, but the number of calls by the dealers forms only a small fraction (8%) of all calls.

The call agent records the relevant some information, like the date of the call, name of customer, the product, and a brief description of the problem, the possible cause and the solution. This information is later on send to the company via Intranet and feedback reports.

Just as in the case of High-End, I will now evaluate the speed of the field feedback flow and its value for finding the root causes of field failures.

- Initial Investigation Centre (IIC)

As explained before, this centre had to look for the root causes of the first 50 to 80 products with a serious field complaint. An extensive report with all the details about the problem, the root cause and, if possible, solutions was fed back to QD. After I finished my research in High-Volume, the last IIC was closed down. At the moment High-Volume does not look for the root causes of field failures anymore.

Normally the IIC really found the root cause of a field failure. Nevertheless, the IIC information is left outside of the scope of this project, as an IIC investigation only started in case unsatisfactory product performance was expected; it was not common practise for all products.

From the point of view of *fast* field feedback the contribution of the IIC should not be overestimated, because it depends on the pipeline between production start and sale of the product. This pipeline was normally between 2 and 9 months. In particular given the short period during which a product is produced, such a pipeline is quite considerable.

- Customer

The customer can directly contact High-Volume via e-mail. In this e-mail a description of the problem should be given. The information is in the form of free text. No matter how potentially valuable this information might be, interviews within High-Volume show that it is hardly used. This is because the information is not structured and there are so many e-mails.

Consequently, the information gathered via e-mail is left outside of the scope of this project, as the information does not seem to be very valuable for root-cause finding.

- Dealer

The customer can contact the dealer, when encountering a problem with or in using his product. Besides selling the product, the dealer's task is to forward technical product problems to (its own) service centre and to answer non-technical questions, if possible, or else forward the questions to the CCC. A customer can contact a dealer for many different reasons and the dealer has three standard options.

- *Give general information:* The salesman usually has enough product knowledge and general experience to answer many questions, or to explain the customer how to use his device. Furthermore, the dealer can ask the CCC for information.
- *Escalation to the National Sales Organisation:* This is done in case of difficult and serious questions, missing parts, or products that are dead on arrival. The National Sales Organisation will support and supply the dealer on the one hand and report the issue to Customer Interface on the other hand.
- *Repair Requests:* When it appears that the product needs a repair, then the dealer will send the device to a service centre. This service centre could be part of the dealer, a High-Volume central service centre or a third party.

No data is saved about the customer contacts with the dealers, and therefore no feedback to High-Volume exists. The quality department (QD) only indirectly takes notes of these contacts if a specific contact leads to a repair action or a call to the CCC.

For all these reasons the information from the dealer is considered to be not useful for quality improvements, and is left outside the scope of this project.

- Service Centres

One of the interfaces a customer can contact is a service centre. This is in case the customer believes the product needs a repair. Sometimes the product goes to a service centre via the dealer.

When the product is within warranty (1 year) the customer has the right of a free repair. The replaced parts also have a 1-year warranty from the replace date on.

Many service centres are outsourced and some of the dealers have their own service centre.

Service centres are forced to minimise costs for spare parts. They look at the component level for defect. But as stated by High-Volume's world audio service manager at the end of 2000: "Due to the various uplifts, contribution margins and profit targets, our spare parts supplied to the service centres have rather high prices. The result is, that in the near future, we will have to decide for replacement actions instead of repair."

The three sorts of product quality feedback find their origin at the job sheets.

- Field Call Rate (FCR)
- Repair Pareto
- Customer complaints

Most of this information is updated monthly on intranet. A combination of all three types of information is presented in management reports that appear 2 to 4 times a year.

The Field Call Rate information is discussed in the chapter about field feedback of statistical information (chapter 7).

The repair Pareto and customer feedback are later evaluated on speed and level of detail for finding root causes of field failures.

- National Sales Organization (NSO)

When a batch of products has been produced, it is sent to a Regional Logistic Centre (RLC). RLC checks the products, and can approve them or reject them. Not rejected batches are sent to the NSOs and the dealers. When a product is damaged during the transfer from the RLC to the dealer, or is found not to function according to specification, then this will be reported to the NSO. The NSO handles the replacing and the financial consequences and forwards the reports to High-Volume, which has the responsibility that the information ends at the right desk.

The NSOs are also responsible for paying the service centres. Furthermore, the NSOs are the communication link between High-Volume and the dealers. The Information that High-Volume receives/exchanges with NSOs has a financial or logistics nature. This information has no relation with finding root-causes of failures. Thus the information from NSO will not be discussed in this thesis.

3.2.2 Usability for finding root-causes

The importance of finding the root-causes follows from the necessity of improving the product and preventing the reoccurring of old problems in the same generation and/or every next product generation.

Depending on the level of change of a product from one generation to another, there are different things to consider. When the product does not differ much from a previous generation, it is relatively easy to predict already during development its behaviour on the market given the behaviour of the previous generation. However, this assumes that this last information is available and used during all the phases of Product Realisation Process.

When a product has a new functionality, it needs special attention, as it is not totally clear how the user will use all of the new functions. Furthermore, even if for the main part of the product a standard design is used, it is still not clear if the interaction between the standard part and the new aspects will give unpredicted failures.

The impact of failures also gives different wants to the field feedback. In case of safety problems or major reliability problems, it is necessary to make changes immediately, in the present generation. In the case where the problem is minor, the changes can be implemented in the next generation, although this can cause frustration at the side of the customer.

- CCC feedback and RCA

Customers who encounter a problem with their product can go back to the dealer, visit a service centre, or call the Customer Contact Centre. Most customers bring their device back to the dealer and the dealer forwards the devices to a service centre. Only a small part of the customers call the Customer Contact Centre. The next chart (figure 6.8) shows the difference between the numbers of problems reported by a dealer or service centre and by the Customer Contact Centre. This graph is based on figures from January 2001 until October 2001, and it indicates that most customers do not call the Customer Contact Centre in case of a problem with their device.

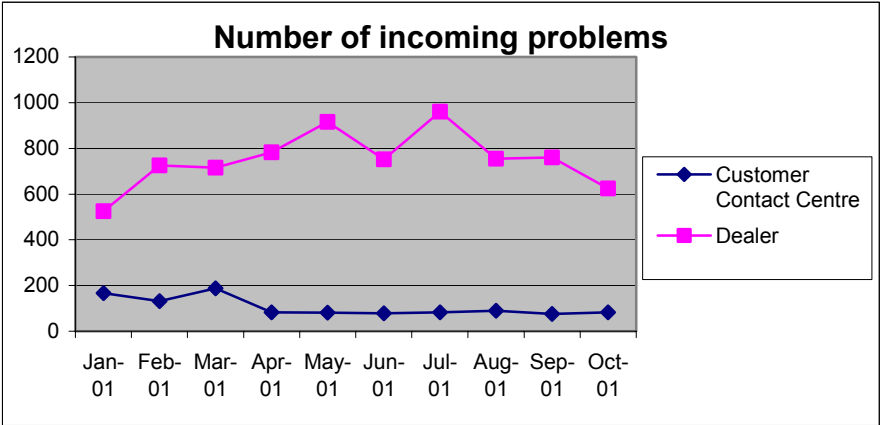


Figure 6.8 Number of Incoming problems

Unfortunately, there is no information available about the fraction of customers that aborted their calls to the CCC because of excessive (in the opinion of the customer) waiting time.

When a customer has a problem, he or she can call the Customer Contact Centre. First, the incoming calls are registered and the call agent fills in the consumer details. The exact complaint or question of the customer is typed in; this is called free text. The call agent can launch a database (DB) to assist the agent to solve the problem. DB is a tool, which is created by the engineers of High-Volume to assist the call centre agents to resolve the problems. DB is a database with a lot of different symptoms of field problems. In addition, this tool provides the agent with structured questions to help identify the root cause of the symptom.

The DB however, does not cover all the symptoms. It is also possible that the customer just has some questions, complaints or remarks. In these cases, the agent just types in

the free text. The call agent will then try to help the customer by using his/her knowledge to solve the problem, or the customer is referred to the service centre when the problem cannot be solved. The agent does not always log into the advance DB, because he might realise that the customer meant something else. In this case the call data will be cancelled, or the agent will try to log in again with other problem symptoms. This time, he will start the advance DB, which consists of several well-structured questions to detect the root cause of the problem.

The knowledge base gives the agent the opportunity to ask the customer structured questions in order to find the root cause of his/her problem. Basically, when the DB is used there are two possibilities. The first occurs when the case is resolved after asking several structured questions. In practise, this occurs when the customer does not know how to operate the set, or expected the set to react differently. These cases will not escalate further to the service centre. The second possibility is that even after the agent asked structured questions, he still is not able to solve the problem faced by the customer. It is now almost sure that there is a real technical problem and therefore the customer is advised to return the set to a service centre. This means that the case escalates to the service centre and that it will imply an increase in the Field Call Rate.

The free text data is often not more than one sentence stating the problem, which the customer faced. However, the root cause of the problem as well as the fact whether or not the case escalated to the service centre is hardly ever recorded. Using case data, it is very hard to figure out whether the customer did not know how to operate the set or whether it was a real technical failure. This makes the free text data a relatively unreliable source of information for analysing root causes of technical and operational problems.

The conclusion can be drawn that a lot of information is unreliable for detecting the actual root causes of problems. The main reasons are that the root cause of the problem is either not given or no further questions are asked by the call centre agents to detect the root cause. It is remarkable that the agents do not always log into the database. The initial analysis showed that the call agents only made use of the database in 23% of the cases. The question then arises: why is the DB only used in 23% of the phone calls? After going through the available data, some reasons can be given that might explain the low use of the DB:

- In the event of re-occurring problems, the agent already knows which questions he should ask or how to solve the problem. Therefore he/she does not start up the DB.
- The call agents are working under time pressure. They are expected to help as many customers within as little time as possible and starting up and using the DB takes time. The time required to start a DB differs per product, however it was identified [Boe01] that the required time is too long in relation with the time pressure that call agents are put under. This might explain why agents avoid using the DB in some cases.
- The main task of CCC is to help customers and not to record reliable data for feedback to the product creation process. Cost and time drivers are very clearly

the most important determinants for CCC, while the feedback of information seems to be subservient.

[Boe01] shows that 77% of the CCC data consists of the unreliable case free text data.

- IIC feedback and RCA

As said before, the first 50 to 80 devices that are brought in for repair after commercial release were sent to the IIC. These products were thoroughly examined and the engineers of IIC seriously searched for root causes behind the malfunctioning device.

The IIC only gave insight in the root causes, if the failure description from the customer was clear and the failure was reproducible by the IIC. The IIC was not allowed to contact the customer if the failure description is unclear and the failure is not reproducible; in this case the IIC reported: fault not found. On average 10% of the reported failures were classified as 'Fault Not Found'. This is far less than the 46% 'Fault Not Found' for all the feedback sources together (jobsheet, IIC and Customer Contact Centre). Unfortunately, there is no information available about the spread of root cause defects by the RCAC in the first 50-80 defect for a product. This means that the IIC scores above average for finding root causes. This is probably the result of the fact that the IIC concept was initiated to find weak points of a product, immediately after the first products were brought in for service. In principle, all devices that were sent to the IIC had 'serious' failures.

The *service centre* just repairs the device, for example by exchanging a problematic module. If the device then functions, the service centre did its job. The IIC really investigated the failures, instead of just repairing it, therefore the quality of the feedback from the IIC was better than the quality of the feedback from the service centre (gained out of the jobsheet). A weak point of the IIC was that if the failure was not reproducible by the IIC, no root cause would be found, because the IIC was not allowed to investigate the product in its original setting at the house of the client. This however is true for the Service Centres as well.

The IIC forwarded the quality related feedback to QD. The QD investigated the feedback. If the QD found 'interesting' failures, the QD asked the IIC for extra information. If the IIC did not have any extra information, then they could not contact the owner of the problematic device to forward it.

This makes clear that there was only a limited possibility to trace the problem. If the problematic device was still in the possession of the IIC, the QD could have the device for further investigation. The QD could not contact the customer and could not get not playable audio CDs or not playable MP3 files which were the reason for the customer to return his device.

- Feedback from Service Centres and RCA

All repair actions executed by all repair centres are reported by the jobsheet. The jobsheet contains a description of the repair action, the serial number and a description and the position of the replaced module or component. All jobsheets together with the warranty claims of a certain region are collected at one place.

The field feedback on a particular type of audio equipment, a CDR player, was investigated and it was found that in 24 weeks (about six months after production start) 73 devices were brought in for service. (Note that this amount can be higher, because service centres have three months to report the repair to the jobsheet) The number of *different* failures reported in the jobsheet is unknown, because the feedback from the jobsheet gives hardly any insight into the failures. The first feedback (from the first 20 problematic devices) was available for QD in week 28. This means that within six months after production start no feedback was available for QD. The jobsheet, therefore, scores negative on the quantity of feedback within six months after production start. From the past, it is known that the jobsheet generates a huge quantity of feedback, but it takes a long time, until the feedback comes in.

As said before, the feedback from the jobsheet is not useful for a root cause analysis, because the jobsheet hardly gives any detailed insight into the problem, the cause or the solution. The jobsheet therefore scores negative on the criterion quality of the feedback.

It is not possible to trace the owner from a problematic device for asking him or her extra information, if the service centre does not find the failure.

If QD receives the feedback of a certain repair from a service centre, then the device itself is already returned to the customer, or the customer received a new device, and the old device is thrown away. Furthermore, company policy forbids that the customer is contacted about his device. As a result, it is impossible for the QD to trace a certain problematic device, and let the device come to QD for further investigation.

Because the customer with a problematic device is not traceable, he or she cannot deliver problematic audio CDs, or problematic MP3 files.

The jobsheet, however, can be used to make an analysis of the time between production of devices and selling them to the end user. For some models CD recorders this is done in paragraph 3.2.3.

Every month the service organisation analyses the jobsheets and comes up with repair Pareto diagrams. These Pareto analyses give more insight in which parts have been replaced/repared and the frequency of the specific problem. These Pareto analyses are calculated for the time period of a year, but can also be calculated for specific months. They are usually calculated for a product within a certain region and are viewable via the Intranet.

3.2.3 Speed

No matter how detailed field feedback information is and how much it can help in finding root causes, if the information is not available when it is needed, it is of little value for the current or possibly next immediate generation.

- CCC feedback and speed

Graphs on the call volume for few products were investigated. The time between production start fluctuates depending of the product. However a minimum of 3,5 months is required for receiving the first customer calls.

Another 2.5 months pass before sufficient feedback for a informal decision is collected.

This shows that the feedback from CCC scores negative on speed.

- IIC feedback and speed

It took 25 weeks from production start until the feedback about the first 8 CDR players reached QD. It took 30 weeks until the feedback from all failures reached QD. This is about six months for the first feedback and longer then six months for all feedback. Therefore, the IIC scored negative on the criterion speed of the feedback.

- SC feedback and speed

The jobsheets for the CDR players were investigated for the first 24 weeks after production start was investigated. As said before, all devices brought in for service are reported via jobsheets. Service centres have three months to report the service via a jobsheet, but probably they report services much faster, because service centres get paid by High-Volume *after* they have reported the service via a jobsheet. The number of returned devices per week is shown by figure 2.5 (chapter 2). Week one is the week right after production start.

Figure 2.5 shows that the first device was brought in 12 weeks after the production start. The number of incoming devices increases over time, except in the last week, in which the number of devices decreased. This is not because fewer devices were brought in for service, but this is because not all services were reported on a jobsheet during the investigation. From production start it takes 20 weeks until 20 devices where brought in for service. It takes an average of one month until the services are reported on a jobsheet. The jobsheet is reported monthly to QD. All together, it takes a minimum of 28 weeks after production start until QD receives the first jobsheet feedback. This means that the first feedback from the jobsheet reaches QD more than six months after production start. The jobsheet scores negative on the criterion speed of the feedback.

3.3 Conclusions Case High-Volume

High-Volume has 3 main suppliers of reliability field feedback information. Those are Service Centres, IIC, and call centres.

All those sources highly depend on the pipeline (cf. figure 2.6) between product introduction and product sold.

The speed of the quality related feedback from customers itself is not the major problem. The feedback processing time is very good (1-2 weeks) and probably cannot be decreased. If QD really would like to increase the speed of the feedback after production start, then the time between production start and the first occurrence of an

after sales service request has to be decreased. This feedback however cannot be influenced.

4 CONCLUSIONS

From all the evidences presented in the text the following conclusions can be made:

High-End

High-End receives engineering feedback form service centres and from selected dealers. This feedback is useful for root cause analyses; however, the feedback flow takes months.

The main characteristics of High-End are:

1. Slow innovations
2. When innovation is done the product is totally different
3. Relatively long time between production start and production stop
4. Expensive products
5. Relatively small volumes of products
6. Relatively small use of field information for improvement of next generation

In particular the aspects 2, 4 and 6 require that there is a fast field feedback information flow.

For more specific conclusions about High-End I refer to section 2.3.

High-Volume

In relation to finding root cause of a failure, High-Volume receives useful engineering feedback from IIC, service centres and to a limited extend from the call centres.

During my research it was decided by High-Volume to abolish IIC. Since then useful feedback can only be collected by service centres and call centres.

High-Volume has the following characteristics:

1. Fast innovations
2. Stable platform and small innovations from generation to generation
3. Relatively short time between production start and production stop
4. Relatively cheap products
5. Big volumes of products
6. Potentially field information can be used for quality improvement of next generation.

In particular 2 and 6 require that there is a fast field feedback information flow.

All the information sources need a considerable amount of time to supply High-Volume with sufficient information to act on.

For more specific conclusions about High-End I refer to section 3.3.

Both companies

For both companies the following can be concluded:

- Although the two companies have different characteristics, the field feedback systems that should give valuable engineering field information are very similar.
- The field feedback is rather incomplete and not really suitable for root cause analyses.
- The speed of the field failure information flow depends highly on pipelines between production start and the first received complaint.
- There is no direct contact between the person experiencing the problem (customer) and person with most knowledge about the product (development).
- It is hardly possible to improve the field failure feedback flow, because the logistical pipelines cause that field feedback is (too) late anyhow.

Field Feedback of Statistical Quality and Reliability related Information

1 INTRODUCTION

This chapter is about the role of statistical field information in fast reliability improvements. It is partially based on [Pet00a], [San03] and [Ion03].

The chapter answers research question 1 and 2 in relation to statistical field information. In line with the previous chapter, it demonstrates that engineering field information is to be preferred above statistical field information when fast product quality and reliability improvements are wanted/needed.

Section 2 describes the problem areas that can be tackled with the help of statistical information. This section gives a general picture of the problems that consumer electronics manufacturers are confronted with.

Section 3 discusses the so-called warranty call rate, a common reliability metric that gives a moving estimate of the probability, say $F(12)$, that a product will fail within one year after sales to the customer.

Section 4 discusses the effects of incomplete sales information on the estimation of $F(12)$, using a Weibull failure distribution. The emphasis is on estimating $F(12)$ within three months after product launch.

Finally, section 5 presents the conclusions.

2 POINT OF DEPARTURE

When a company wants to find root causes of field failures, it is best to use engineering information, i.e. information about all aspects that are relevant to understand the reason why a customer reports a product failure (chapter 1 section 3). In the very short term (days or weeks), engineering information should provide early feedback on whether the product fulfils customer needs in a safe and reliable way. If not, necessary actions should be taken, such as a design change or changes of the production process, in order to adapt the product to the way it is used. The conclusions should be based on engineering data. This part of the field failure information flow was already discussed in chapter 5.

In the short to intermediate term (weeks or months), field failure information should demonstrate what design and/or production improvements are most wanted in coming generations or in new designs in order to prevent the recurrence of 'old' failure modes in new generations. The main sources of information are engineering data and statistical data about the frequency of problems.

In the long term (several months), field failure information should make clear whether the product reliability is in line with the predictions and to find out whether the company is learning from the past. The answers to these questions should be based on statistical evidence.

From the above it can be concluded that judgment about the overall performance of the product requires statistical analyses of quantitative field failures information.

In order to reduce the risks, manufacturers need to have fast and reliable information about the field behaviour of their innovative products. This information can be used, among other things, for the following reasons:

- If information about the field reliability is available soon after product launch, then it can be used in case the question rises whether the field complaints should lead to a product recall.
- The field reliability determines to some extent the warranty cost, and companies like to have a prediction of the warranty costs as early as possible. Field information gives the possibility to update predictions made earlier in the product creation process.
- Field reliability figures are valuable for a mutual comparison of the reliability of different (generations of) products. They demonstrate which product creation processes are fully under control and which ones need special attention.
- In particular, when innovation from product type to product type is step by step, a fast field feedback information flow offers the opportunity to take immediate action in case an innovation step causes problems. In this way, it can be prevented that the same problem keeps showing up in a number of generations of new products.

In this chapter I focus on the estimation of the failure probability during the warranty period using field failure data. I assume throughout the whole chapter, without loss of generality, that products have a one-year warranty. I refer to [Ohy01] for situations where additional field data are gathered after the warranty period expired. The method that is discussed in section 4, can also be used beyond the warranty period, as long as there are no clear signs of wear-out. As consumer electronics products normally fail only once at most during the warranty period, I only consider the time to first failure.

The focus is on giving a fast estimate of the failure probability using field failure data. For consumer electronics, field data is usually restricted to the time between the purchase date and the date on which the failure is reported. As long as calendar time is proportional to the real characteristic that causes product failure, calendar time is useful information. Technically, however, it is no problem to register and use the most important aspects of customer use, like the number of times the product is switched on, or, in case of a CD writer, the number of CDs that is recorded. The collection and use of this information is, however, not common practice.

Two methods are discussed that can be used to estimate the probability that a product fails during the warranty period. Because in this chapter the warranty period is

assumed to be one year, and time is measured in months, the probability that a product fails during the warranty period is denoted by $F(12)$.

3 WARRANTY CALL RATE

This section concentrates on the Warranty Call Rate (WCR), which is used by several consumer electronics companies, and that has some value in monitoring the product quality over time. The discussion concentrates on the practical value of the WCR given the existing obstacles in collecting the required field failure data.

In section 3.1 the WCR is introduced. Section 3.2 discusses the practical limitations of the WCR given the available field failure data. The conclusions are presented in section 3.3.

3.1 Warranty Call Rate: definition and characteristics

The basic idea behind the WCR is to calculate, retrospectively, the percentage of products that failed during the warranty period. This percentage is updated every month by calculating the WCR using a moving time window. For a warranty period of 12 months, the following working definition can be used:

$$WCR = \frac{\text{total number of repairs under warranty during last year}}{\text{a measure of the number of products under warranty last year}}$$

For simplicity it is assumed that all products that are sold to the customer, are sold on the first day of a month. In order to be able to give a more precise quantitative definition, the following terminology is introduced:

- $R(i)$ = number of repairs under warranty in month i after product launch, with $R(i) = 0$ for $i \leq 0$
- $S(i)$ = number of sales to customer in month i after product launch, with $S(i) = 0$ for $i \leq 0$
- $GP(i)$ = warranty package in month i : $GP(i) = \sum_{j=0}^{11} S(i-j)$, i.e. $GP(i)$ denotes the total number of products under warranty at the end of month i , for $i \geq 1$.

Then $\frac{1}{12} \sum_{j=0}^{11} GP(i-j)$ is a logical measure for the number of products under warranty last year. This leads to the following estimate of $WCR(i)$, for $i \geq 12$:

$$WCR(i) = \frac{\sum_{j=0}^{11} R(i-j)}{\frac{1}{12} \sum_{j=0}^{11} GP(i-j)} \quad (1)$$

Notes

1. For large i , $WCR(i)$ uses the sales of the last 2 years, as can be seen from

$$\sum_{j=0}^{11} GP(i-j) = \sum_{k=0}^{11} \sum_{m=k}^{k+1} S(i-m), \quad \text{for } i \geq 23 \quad (2)$$

2. A strong point of $WCR(i)$ is that it accepts that the product reliability may depend on the production date. In particular, when there is a sudden shift in product reliability by, for example, a (minor) design or production adjustment, this is reflected in $WCR(i)$. This is further discussed in section 3.2.
3. As described before, if the product reliability is not what it should be, then a manufacturer wants to act as soon as possible. Therefore, the manufacturer wants to have as soon as possible a realistic estimate of the product field reliability. The working definition of WCR is based on field information over one full year. As will be clear from section 1, information that becomes available later than one year after product launch, has lost most of its potential value. For this reason $WCR(i)$ is usually also calculated long before the end of the first year after product launch. It goes without saying that in this case WCR is estimated by the following formula:

$$WCR(k) = \frac{\sum_{j=0}^{k-1} R(k-j)}{\frac{1}{12} \sum_{j=0}^{k-1} GP(k-j)}, \quad \text{for } 1 \leq k \leq 12 \quad (3)$$

Note that the factor 12 is a consequence of the length of the warranty period and should therefore not be replaced by k .

3.2 *Warranty Call Rate: practical limitations*

At first sight, $WCR(i)$ seems to be an attractive metric for the probability that a product fails during the warranty period. However, several practical aspects limit the applicability considerably. In this section the sensitivity of the WCR for the following aspects is discussed:

- Influence of sales pattern
- Sensitivity to changes in product reliability
- Influence of product failure distribution
- Delays in reporting field data (in particular the sales date and failure date)
- Need to estimate the WCR shortly after product launch.

Influence of sales pattern

The sales of consumer electronics show a clear seasonal pattern, as is shown by figure 7.1¹. Each year there is a peak from September to December.

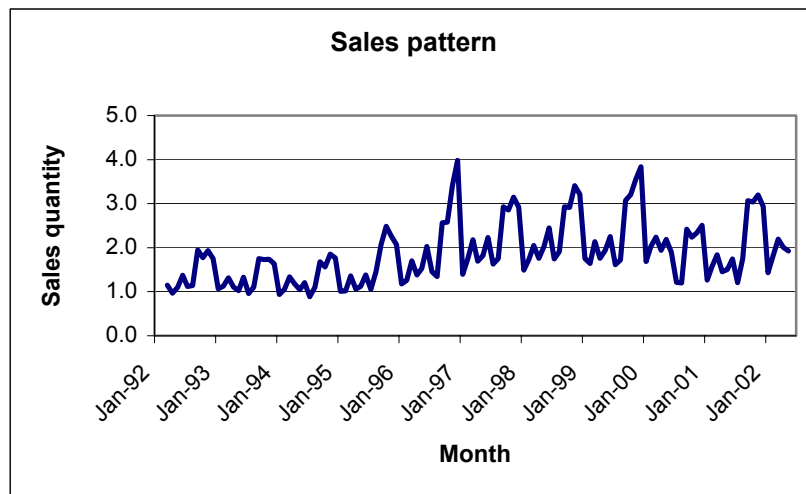


Figure 7.1 Sales pattern of audio products

Because the WCR depends on the sales, one might expect that different sales patterns show different results. However, because the sales of a new month have only a limited influence on the denominator of the WCR, as can be seen from formula (2), after several months the WCR(i) is relatively insensitive for seasonal sales patterns, as well as for increasing and decreasing sales figures.

This is confirmed in a study in which three sales patterns (see figure 7.2) have been used for a situation in which there was a sudden jump in product quality (initially 10% defects per year, from month seven on only 5% defects per year). Figure 7.3 is based on the sales of figure 7.2 and shows the results for the situation in which the defects are uniformly distributed over the warranty period. (Note that the values on the vertical axis in this figure are given in reverse order. Some companies like to report the WCR in this way. A decreasing line shows a decreasing product quality and an increasing line shows an increasing product quality.)

As expected, the different sales patterns have only a limited effect on the WCR. Figure 7.3 also shows, not surprisingly, that increasing sales figures are beneficial for the detection of changes in the product reliability.

¹ On request by the company where we collected the data, the sales figures have been rescaled.

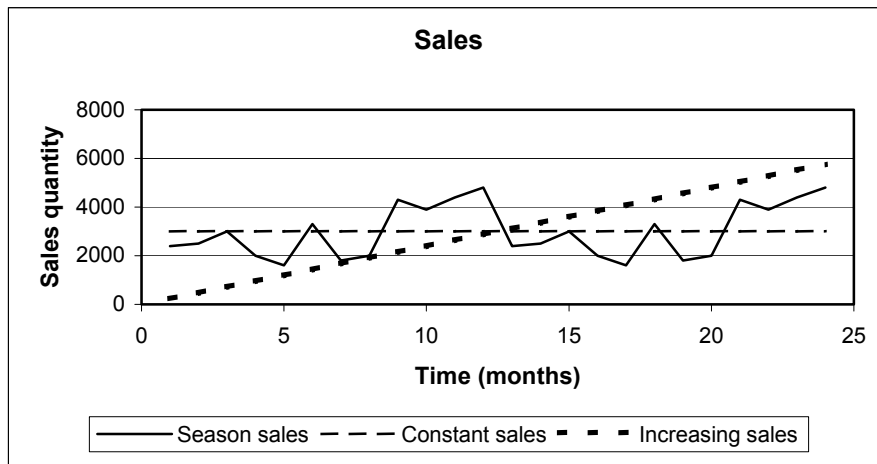


Figure 7.2 Sales pattern used in figure 7.3

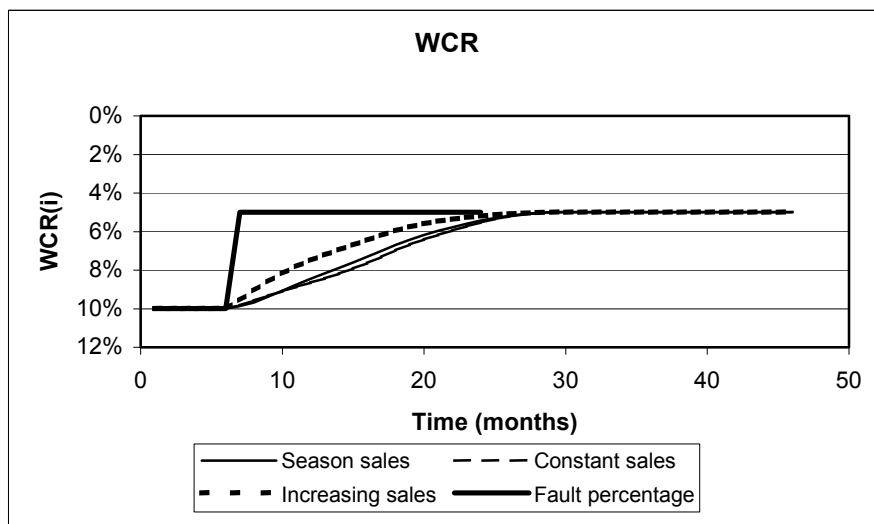


Figure 7.3 WCR(i) resulting from figure 2, using a quality jump in month seven

Sensitivity to changes in product reliability

Although the influence of the sales pattern is minimal, figure 7.3 shows a very relevant phenomenon: there is a huge time delay in the reported WCR(i), what is a direct consequence, of course, of the way the WCR(i) has been defined. The real fault percentage from month 7 onwards is 5% but the reported WCR shows this 5% only after month 29. Therefore, there is a delay of almost two years. This proves that the WCR is not able to detect changes in product reliability within a practically useful time span. Nevertheless, companies base their decisions on the WCR (see also section 3.4).

Influence of product failure distribution

During the important first year after product launch, the failure distribution has a pronounced effect on WCR(i). This can easily be seen by comparing two failure distributions, each with 5% product failures in the first year. Suppose, that for the first

distribution all these failures happen in the first month and for the second distribution all failures happen in month 12. Then formula (3) makes clear that for the first product $WCR(k)$ is a decreasing function of k , for $k = 1, 2, \dots, 12$; while for the second product $WCR(k) = 0$ for $k = 1, 2, \dots, 11$, and it jumps in month 12. This restricts the value of $WCR(i)$ considerable, because as explained in the introduction, it is important to have a reasonable estimate of the WCR within a few months.

Delays in reporting field data

Figure 7.4 gives an example of the reported $WCR(i)$ of an audio product².

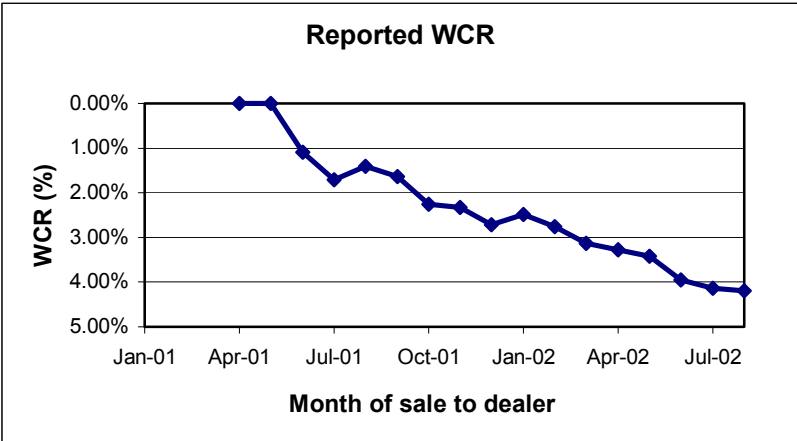


Figure 7.4 Reported WCR

Figure 7.4 indicates a problem: in the beginning the $WCR(i)$ suggests that the product reliability quality is pretty good, and a few months later the product quality seems to be much worse. Of course, this might be the case, but another possible explanation is that the sales-to-customer figures are overstated, which would decrease in particular the values of $WCR(i)$ for small values of i . This explanation is quite likely if a company has only information about the sales to the dealer and has no information about the sales to the customer. The correctness of the conjecture that the sales are overstated can be checked using the products that failed during the warranty period. If a product fails during the warranty period, the owner of the product will usually turn to the dealer or to an official service centre in order to get the product repaired. For the warranty claim, the sales receipt has to be shown. This receipt together with the series number establishes clearly how long the product stays with the dealer.

In the following I suppose that the stock is kept in a ‘suitable’ environment, meaning that a relatively long time in stock does not effect the distribution of the time to failure. Then it is safe to suppose that the distribution of the time to sales is the same for

² All WCRs presented in this paper are known to the authors, but for obvious reasons the scales have been transformed in such a way that the WCRs do not give the real field values.

products that fail during the warranty period, as it is for products that survive the warranty period.

It seems logical that relatively expensive products spend less time with the dealer than relatively cheap products, because dealers do not like to invest a lot of money in storing many expensive products. So, the time on stock will depend on the type of product. Based on warranty information about high volume audio products, we found the following data:

- It may take almost 3 years before all products of a particular type have been sold
- On average about 80% of the products are sold within 10 months
- In the first two months about 20% of the products is sold

3.3 Need to estimate the WCR shortly after product launch

It is important to predict within a few months the WCR for the whole warranty period, i.e. WCR(12). For this purpose, a lot of WCR-graphs of audio products are studied. Focus is on the first three values of the reported WCR(i). By way of example, figure 7.5 gives the reported WCR of four comparable CD portables³. The figure shows that the WCR behaviour in the first three months after market introduction, i.e. supply to dealer, does not give a reliable prediction for the WCR after one year. Note that after 17 months the WCR is still in a transitory state.

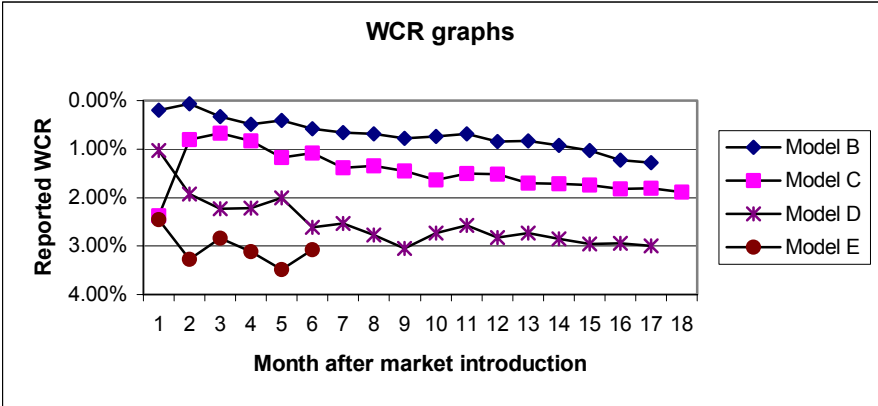


Figure 7.5 WCR graphs of four audio products

³ The real WCR values are known to the authors, but for obvious reasons these figures have been transformed in a linear way.

3.4 Discussion with respect to WCR

According to the formula, the WCR depends on the number of repairs, the number of sales and the warranty period. The practical value of the WCR is very limited because of a number of reasons. The most important ones are the following:

- After some time, a trend in sales has a minimal influence on the WCR, because of the weighted sales average in the denominator of the formula. However, during the very first months after product launch, the situation is different (see formula (3)).
- Changes in product quality, like disasters in production, manifest themselves only after a long delay (see figure 7.3). Manufacturers are interested in information about this type of disasters, but the WCR is not a very attractive metric for this phenomenon.
- The reported WCR depends on the product failure distribution. An unpleasant consequence is that during the first months after the product launch, the WCR can give a wrong impression about the product quality. Again, this proves that the WCR is not useful for fast quality feedback.
- The formulas (1) and (3) require that the number of products on the market are known. The companies I have seen register only the sales to the dealers and not the sales to the customers. In particular shortly after the market launch of a product, the WCR(i) is sensitive for uncertainties in the number of sales to the customers.
- It usually takes two or three months before a warranty repair is reported to the manufacturer. This is one of the reasons why the estimated WCR(i) values during the first months are lower than they should be, what results in too optimistic estimates of the product reliability. In fact this delay of two or three months is an agreement between the manufacturer and the repair shops.

Overall, it is concluded that the WCR might be a useful metric in case generations of products stay on the market for a long period. However, innovative consumer electronics hardly stay on the market for more than one year. Therefore the WCR is not a very useful metric for predicting the percentage of failed products during the warranty period of these products. Moreover, the WCR is useless for monitoring purposes, because it reacts far too slow on changes in the product reliability. In industry sometimes employees are judged on improvements in product quality while the WCR is used as the metric for quality improvement. As changes in product quality cannot be monitored by means of the WCR, this is a demotivating system.

Predicting requires a model. One of the problems is that the WCR is not based on a statistical product failure model. It is based on the assumption that the WCR formula gives accurate information about the product quality, already a few months after product launch. Partly because of the delay between the moment the product failed and the moment this failure is processed in the WCR figure, this assumption is not satisfied. In the next section a statistical model will be discussed and analysed on its value for predicting the product reliability early after market launch.

4 ESTIMATING WEIBULL PARAMETERS

For financial reasons companies want to have a timely and accurate prediction of the product quality of new products. Such a prediction does not improve the product quality, but based on such a prediction it can be decided, for example, to make a reservation for warranty costs, or to take the product of the market.

In this section, it is assumed that the product lifetime can be modelled by a two-parameter Weibull distribution with a scale and a shape parameter. The possibilities are discussed to estimate these parameters, because this leads straightforward to an estimate of the failure probability during the warranty period. Because of the need to have an indication about the product reliability within a few months, only field failure data about the first three months of customer use will be used.

4.1 Weibull estimation for known sales dates

In practice the sales dates of the products to the customers are not always known; in particular the sales dates of the products that did not yet break down are often unknown. In this section it is assumed that the sales dates are known on a monthly basis. This means that it is only known how many products have been sold in each month, but the sales dates of the individual products are not known. As the companies I have studied only collect information about the dates of sale to the dealers and not about the dates of sale to the customers, it is also relevant to study the situation for which the dates of sale to the customers are not known; this is discussed in section 4.2.

Terminology: when I use ‘date of sale’ I mean ‘date of sale to the customer’ unless another meaning is explicitly mentioned.

In the following it is assumed that there is a failure model available. If such a model is not available, one could make use of experts’ opinions that are updated using Bayesian methods [San91], but that is outside the scope of this thesis.

As mentioned before, it is assumed that the class of Weibull distribution functions reflects the product failure behaviour. It is assumed that the differences between the real failure data and the warranty claim data as collected by the manufacturers can be ignored.

The two-parameter Weibull distribution is defined by

$$F(t) = 1 - e^{-\alpha t^\beta}, \text{ where } t > 0 \text{ and } \alpha, \beta > 0.$$

It is the intension to estimate the parameters α and β as early as possible after product launch. If all sales dates are known, then the maximum likelihood (ML) estimates of the parameters can easily be calculated. As the sales dates I have seen are classified in months, the situation is more complicated. The likelihood function can only accurately be calculated in case there is information available about the exact dates of sale and about the exact dates of failure. In case there is no additional information, it seems logical to assume that all sales are uniformly distributed over the entire month. A much more simple, but less accurate, approach assumes that all products are sold on

the first day of the month. This approach is used in this chapter. In section 4.2 a more general approach is given

Although the discussion concentrates on the estimation of α and β three months after product launch, first the situations after one and after two months are shortly discussed.

4.1.1 After one month

Let S denote the number of products sold in month 1, and let R denote the number of products that failed during that same month. It is assumed that all S products have been sold on the first day of the month. Then the likelihood function L_1 based on data of one month reduces to the following simple expression:

$$L_1 = F(1)^R (1 - F(1))^{S-R}$$

Using the Weibull distribution this leads to the following loglikelihood V_1 :

$$\begin{aligned} V_1 = \ln L_1 &= R \ln F(1) + (S - R) \ln(1 - F(1)) \\ &= R \ln(1 - e^{-\alpha}) - \alpha(S - R) \end{aligned}$$

This shows that it is only possible to estimate the parameter α . In case it is likely that the shape parameter β is equal to the shape parameter of similar products from a previous generation, one might concentrate on the estimation of α , but a more attractive solution might be to use sales and failure data about the first two or three months.

4.1.2 After two months

Assume that data from the first as well as from the second month of product use is available. Again all sales are concentrated on the first day of each month. Let S_i be the number of products bought by the customer on the first day of month i , and let R_{ij} , $j \geq i$, denote the number of products sold on day one of month i that fail in month j (see Table 7.1). Let the sales and repair data be known.

Table 7.1: Field data after two months

Sold in month	# sold	# failures in month 1	# failures in month 2
1	S_1	R_{11}	R_{12}
2	S_2	0	R_{22}

The parameters α and β are estimated using the maximum likelihood method. For more information about the ML method in case of censored data see [Mee98].

Let $F(i)$ denote the Weibull failure probability at the end of month i . Let L_2 refer to the fact that only field data is used that is available about the first two months. By definition the likelihood function L_2 looks as follows

$$L_2 = [F(1)]^{R_{11}+R_{22}} [F(2)-F(1)]^{R_{12}} [1-F(1)]^{S_2-R_{22}} [1-F(2)]^{S_1-(R_{11}+R_{12})}$$

The equations $\partial \ln(L_2)/\partial \alpha = 0$ and $\partial \ln(L_2)/\partial \beta = 0$ give the following ML estimators

$\hat{\alpha}_2$ and $\hat{\beta}_2$:

$$\hat{\alpha}_2 = \ln\left(\frac{S_1 + S_2}{S_1 - R_{11} + S_2 - R_{22}}\right)$$

$$\hat{\beta}_2 = \frac{\ln(2)}{\ln\left(\frac{S_1 + S_2}{S_1 - R_{11} + S_2 - R_{22}}\right)} \ln\left(\ln\frac{(S_1 + S_2)(S_1 - R_{11})}{(S_1 - R_{11} + S_2 - R_{22})(S_1 - R_{11} - R_{12})}\right)$$

Hence, the fitted Weibull distribution function is estimated by

$$\hat{F}_2(t) = 1 - e^{-\hat{\alpha}_2 t^{\hat{\beta}_2}}, \text{ for } t \geq 0$$

This leads immediately to the estimate $\hat{F}_2(12)$ of the failure probability during the warranty period.

4.1.3 After three months

From now on only the situation at the end of month three is discussed. This situation is discussed more thoroughly. Again all sales are concentrated on the first day of each month. Assume that all the monthly sales and repair figures of the first three months are known (see table 7.2).

Table 7.2: Field data after three months

Sold in month	# sold	# failures in month 1	# failures in month 2	# failures in month 3
1	S_1	R_{11}	R_{12}	R_{13}
2	S_2	0	R_{22}	R_{23}
3	S_3	0	0	R_{33}

In this case the likelihood function, L_3 , is the following:

$$L_3 = [F(1)]^{R_{11}+R_{22}+R_{33}} [F(2)-F(1)]^{R_{12}+R_{23}} [F(3)-F(2)]^{R_{13}} \cdot [1-F(1)]^{S_3-R_{33}} [1-F(2)]^{S_2-(R_{22}+R_{23})} [1-F(3)]^{S_1-(R_{11}+R_{12}+R_{13})} \quad (4)$$

Due to the analytical complexity, the system formed by the equations $\partial \ln(L_3)/\partial \alpha = 0$ and $\partial \ln(L_3)/\partial \beta = 0$ is solved numerically (using Matlab). This gives the estimates $\hat{\alpha}_3$ and $\hat{\beta}_3$, and therefore to the following fitted distribution function

$$\hat{F}_3(t) = 1 - e^{-\hat{\alpha}_3 t^{\hat{\beta}_3}}.$$

(The calculations can also be left to standard software, for example to Weibull ++ from Reliasoft.)

In order to check the accuracy of this method, the R_{ij} 's are simulated using Weibull distributions with values of α and β that result in more or less reasonable values for the mean and standard deviation of the life time, see table 7.3. The following values for the sales are used: $S_1=243$, $S_2=8771$ and $S_3=7150$; these values correspond with real field values from industry.

The simulation runs as follows. Draw S_1 times from a Weibull failure distribution. Then R_{11} equals the number of realisations less than or equal to 1 (month), R_{12} is the number of realisations between 1 and 2 (months), and R_{13} equals the number of realisations between 2 and 3 (months). In a similar way the values for R_{22} , R_{23} and R_{33} are simulated. Implementing the obtained R_{ij} values in $\ln(L_3)$, leads to the ML estimates $\hat{\alpha}_3$ and $\hat{\beta}_3$ of α and β .

This procedure is repeated 100 times, and the mean and standard deviation of the generated values $\hat{\alpha}_3$ and $\hat{\beta}_3$ of α and β are computed (see table 7.3). The expectation μ and standard deviation σ of the Weibull(α, β) distribution indicate whether the values of α, β are realistic.

Table 7.3: Results of 100 simulations of the MLE of the parameters of a Weibull(α, β) failure distribution (3 months data)

α	β	mean($\hat{\alpha}_3$)	mean($\hat{\beta}_3$)	stdev($\hat{\alpha}_3$)	stdev($\hat{\beta}_3$)	μ	σ
0.001	1	0.0010	1.014	0.00022	0.288	1000	1000
0.001	1.8	0.0010	1.790	0.00025	0.366	41	24
0.001	2	0.0010	2.035	0.00025	0.326	28	15
0.01	1	0.0099	1.002	0.00074	0.082	100	100
0.01	1.2	0.0100	1.220	0.00087	0.111	44	37
0.05	0.8	0.0499	0.804	0.0020	0.042	48	60
0.05	1	0.0502	1.000	0.0018	0.045	20	20
0.1	0.7	0.0996	0.703	0.0026	0.027	34	50
0.1	0.8	0.1002	0.800	0.0026	0.028	20	25
0.1	1	0.1000	0.996	0.0024	0.033	10	10

The table shows that the estimation of α and β is quite good. The real judgement of the performance of the ML method is given, of course, by a comparison of the real value of $F(12)$ and $\hat{F}_3(12)$. The largest difference for the 10 distributions used in table 7.3 is 0.011, what suggests that the procedure is suitable for practical applications.

4.1.4 Alternative approach

The approach that was presented in the sections 4.1.1 up to and including 4.1.3 is based on a straightforward calculation of the likelihood function. Martin Newby (City University London, UK) suggested (private communication) a more general approach using transition probabilities between the different states in which a product can be. Because this approach leads to valuable generalisations, like customers who do not report a failure while one is present, it is shortly discussed. The general approach can also handle situations in which failed products are repaired, but that is outside the scope of this thesis. Only the situation without repair is presented, and it is applied to the specific situation that was discussed in the previous section.

One shot devices

Assume that a product can be in one of the four states, good, alarming, faulty, or failed. A product is in the state good when it is able to fulfil its functions and does not warn the customer that it failed. It is in the state alarming when it is able to fulfil its functions but warns the customer that it failed. It is faulty when it failed but there is no warning / the failure is not observed; it is in the state failed when it failed and there is a warning / the failure is observed. The possible transitions between the states are given in table 7.4.

Table 7.4 State transition matrix

From	To			
	State 1: Good	State 2: Alarming	State 3: Faulty	State 4: Failed
State 1: Good	Stays good No warning	Stays good Warning	Fails No warning	Fails Warning
State 2: Alarming	Stays good No warning	Stays good Warning	Fails No warning	Fails Warning
State 2: Faulty			No warning	Warning
State 4: Failed				

Notation:

- p_{ji} the probability of being in state j after i cycles (e.g. months)
- α the probability of a warning given that the system enters the state faulty
- β the probability of no warning when the system is good
- δ the probability of no warning when the system is already in faulty
- η the probability of a warning when the system is in alarming

- R the reliability function of the product
- r_i the probability that a product that is still good at inspection time t_{i-1} survives in the good state until inspection at time t_i , so $r_i = R(t_i)/R(t_{i-1})$ ($i = 0, 1, 2, \dots$ and $t_0 = 0$), with $R(t)$ the survival probability at time t .

The state transition diagram is given in table 7.5.

Table 7.5 State transition probabilities

From	To			
	State 1: Good	State 2: Alarming	State 3: Faulty	State 4: Failed
State 1: Good	$r_i \beta$	$r_i (1 - \beta)$	$(1 - r_i)(1 - \alpha)$	$(1 - r_i)\alpha$
State 2: Alarming	$r_i (1 - \eta)$	$r_i \eta$	$(1 - r_i)(1 - \alpha)$	$(1 - r_i)\alpha$
State 3: Faulty			δ	$1 - \delta$
State 4: Failed				1

Table 7.5 leads to the following equations:

$$p_{1,i} = r_i \beta p_{1,i-1} + r_i (1 - \eta) p_{2,i-1}$$

$$p_{2,i} = r_i (1 - \beta) p_{1,i-1} + r_i \eta p_{2,i-1}$$

$$p_{3,i} = (1 - r_i)(1 - \alpha) p_{1,i-1} + (1 - r_i)(1 - \alpha) p_{2,i-1} + \delta p_{3,i-1}$$

$$p_{4,i} = (1 - r_i)\alpha p_{1,i-1} + (1 - r_i)\eta p_{2,i-1} + (1 - \delta) p_{3,i-1} + p_{4,i-1}$$

and, of course, $\sum_{j=1}^4 p_{ji} = 1$ for $i = 0, 1, 2, \dots$. The initial situation is $p_{1,0} = 1$, $p_{2,0} = p_{3,0} = p_{4,0} = 0$.

For the special case that is central in section 4.1, there are only two states: a product is good or a product failed. This means that $\alpha = \beta = 1$, while the parameters δ and η are irrelevant. In this situation the equations reduce to simple ones:

$$p_{1,i} = r_i p_{1,i-1}$$

$$p_{4,i} = [(1 - r_i)] p_{1,i-1} + p_{4,i-1}$$

with $p_{1,0} = 1, p_{4,0} = 0$.

Say, on day 1 of the first month N_1 good products are sold of which x_k fail in month k ($k=1, 2, \dots$). The number of products that enter month $k+1$ equals

$$N_{k+1} = N_k - x_k, k=1, 2, 3, \dots$$

If X_k denotes the random variable that describes the number of failures in month k , then X_k follows a binomial distribution:

$$P(X_k = x_k) = \binom{N_k}{x_k} (1-r_k)^{x_k} r_k^{N_k-x_k} \quad k=1, 2, \dots$$

This gives the following likelihood (dropping any terms which are independent of parameters):

$$L(\theta|x_1, \dots, x_m) = \prod_{j=1}^m P(X_j = x_j) \\ \propto \prod_{j=1}^m (1-r_j)^{x_j} r_j^{N_j-x_j}$$

This leads to the following expression for the loglikelihood:

$$V_m = \ln L(\theta|x_1, \dots, x_m) \\ = \sum_{j=1}^m [x_j \ln(1-r_j) + (N_j - x_j) \ln r_j]$$

Using $R(t_0) = 1$, V_m can be reduced to

$$V_m = N_{m+1} \ln R(t_m) + \sum_{j=1}^m x_j \ln(R(t_{j-1}) - R(t_j))$$

If, again, the Weibull distribution is chosen as failure distribution, it can be shown that the loglikelihood V_m is equal to the likelihood that was figured out in the previous section.

It will be clear that there are many interesting situations for which this general model leads straightforward to a solution. For the simple model that is discussed in this section 4.1, the general model has no advantages.

4.2 Weibull estimation for unknown sales dates

In practice, the manufacturer often only knows the sales dates for products that have a warranty claim during the warranty period. For the other products, the manufacturer only knows the dates the products were shipped to the dealer. In order to solve this problem, it is assumed that the shop time, defined as the time between sales to dealer and sales to customer, follows a known distribution. In practice, it should be possible to estimate this distribution via the distribution of the shop time for a previous generation of products. For this previous generation the shop time can be estimated using the warranty repair data, because for warranty repairs all relevant dates are known. (Just as in section 3.2 this requires that the stock is kept in a 'suitable' environment). The advantage of this approach is that we do not need the dates of the sales to the customer; the dates of sales to the dealer, together with the distribution of the shop time, give enough information. This approach is used in this section.

Unfortunately, I was unable to collect useful real field data about the shop time distribution, therefore it was not possible to choose a shop time distribution based on field data. Therefore the estimation procedure is illustrated using Weibull distributions for the shop time, but any other distribution can be used as well. As the estimation procedure is, again, based on the maximum likelihood method, it is even possible to

estimate the parameters of the shop time together with the parameters of the failure time distribution. In this section, however, it is supposed that the shop time distribution is fully specified.

Note

In section 4.1 it was assumed that all products are sold on the first day of the month. The method that is presented in this section, using a shop time, can be used to get rid of that assumption.

As before R_{ij} denotes the number of products that are sold in month i and fail in month j . The ML method requires the likelihood function of the R_{ij} 's. Let W denote the Weibull(γ, δ) distribution of the shop time, that is:

$$1 - W(t) = e^{-\gamma t^\delta}, \quad t > 0, \gamma > 0, \delta > 0$$

As before, Weibull(α, β) is used for the failure time distribution of the product in the hands of the customer and the failure times are supposed to be independent of the shop time. Then the total time between the delivery to the dealer and the failure of the product is given by the convolution G :

$$G(t) = \int_0^t \left(1 - e^{-\alpha(t-y)^\beta}\right) w(y) dy$$

with w the density corresponding with W .

It follows that at the end of the first three months, the simultaneous likelihood of all the $S_1 + S_2 + S_3$ products is basically equal to L_3 in formula (4) in section 4.1.3 with the failure time distribution F replaced by the convolution G .

This leads straightforward to the ML estimators of the parameters α and β of the Weibull failure distribution.

In order to find out whether this method gives reasonable estimators of the parameters α and β , simulation is used again. For the shop time distribution two Weibull distribution are used: Weibull(1,2) and Weibull(3,5). The lifetime distributions are equal to the ones in table 7.3.

The R_{ij} 's are simulated analogously to the simulation procedure given in section 4.1, using the convolution G . This procedure is repeated 100 times and the mean and the standard deviation of the 100 estimates $\hat{\alpha}$ and $\hat{\beta}$ are presented in Table 7.6. For these values the procedure gives very good estimates for most values of α and β . For $(\alpha, \beta) = (0.001, 1.8)$ the estimate $\text{mean}(\hat{\beta}_3) = 1.97$ what is a bit large, but not alarming given $\text{stdev}(\hat{\beta}_3) = 0.64$.

Table 7.6: Results of 100 simulations of the ML method with the failure distribution Weibull(α, β) and shop time distribution $W=$ Weibull (γ, δ).

α	β	mean($\hat{\alpha}_3$)	mean($\hat{\beta}_3$)	stdev($\hat{\alpha}_3$)	stdev($\hat{\beta}_3$)	μ	σ	γ	δ
0.001	1	.00092	1.09	.00037	.51	1000	1000	1	2
0.001	1	.00098	1.08	.00029	.40	1000	1000	3	5
0.001	1.8	.00097	1.82	.00031	.85	41	24	1	2
0.001	1.8	.00095	1.97	.00029	.64	41	24	3	5
0.001	2	.00095	2.09	.00035	.82	28	15	1	2
0.001	2	.00097	2.08	.00029	.64	28	15	3	5
0.01	1	.01003	1.003	.00094	.16	100	100	1	2
0.01	1	.01006	.996	.00090	.11	100	100	3	5
0.01	1.2	.00981	1.213	.00096	.17	44	37	1	2
0.01	1.2	.01001	1.218	.00088	.13	44	37	3	5
0.05	0.8	.04972	.807	.00193	.058	48	60	1	2
0.05	0.8	.05003	.800	.00180	.041	48	60	3	5
0.05	1	.04972	.994	.00207	.069	20	20	1	2
0.05	1	.04992	.999	.00185	.047	20	20	3	5
0.1	0.7	.09986	.706	.00313	.039	34	50	1	2
0.1	0.7	.09977	.701	.00312	.029	34	50	3	5
0.1	0.8	.09962	.801	.00254	.044	20	25	1	2
0.1	0.8	.09986	.802	.00285	.026	20	25	3	5
0.1	1	.09974	.999	.00291	.048	10	10	1	2
0.1	1	.10020	1.001	.00258	.032	10	10	3	5

4.3 Discussion with respect to the estimation procedures

In section 4.2 it is assumed that the shop time distribution is fully specified. However, even if it seems reasonable to assume that the class of shop time distribution functions is known, for example the class of Weibull distributions, the parameters of the distribution are usually unknown and have to be estimated. This situation, however, has no effect on the estimation procedure, because the maximum likelihood method easily handles this mathematically more complicated situation.

The attractiveness of F(12) is the fact that it is easy to interpret, much easier than the WCR. From the point of view of the original problem: develop a metric that is able to give an early indication of the product quality, the most important observation is that it is theoretically possible to estimate F(12) quite accurately.

Some of the advantages and disadvantages of using $F(12)$ instead of the WCR are the following.

Advantages

- As has been shown in this chapter, already after a few months the ML estimators are capable of giving accurate product quality estimators. These estimators are suitable for a fast product quality feedback.
- Manufacturers of consumer electronics tend to outsource the repair activities. An external repair centre normally gets a fixed payment for every repair. The height of the payment depends on the product type, but not on the repair. Therefore, an early estimation of the number of repairs gives an early prediction of the warranty costs.
- The sales dates to the customer are normally not known. However, this does not cause a problem, because either the shop time distribution can be estimated on the basis of the jobsheets of the repaired products, or a reasonable class of shop time distributions has to be found and then the estimation of the parameters of the shop time distribution are part of the problem and can be estimated simultaneously with the parameters of the failure time distribution.

Disadvantages

- The ML method assumes that all failure times can be seen as independent realisations from the same Weibull failure distribution. Week to week fluctuations in product quality because of, for example, production problems, are not taken into consideration.
- Repair centres have to send in their jobsheets about repairs before they get their money. It is quite normal that there is a delay of two or three months before the jobsheets are send in. Consequently, the information about the number of warranty repairs comes in with a delay as well. As a result, in practice it does not take two or three months before $F(12)$ can be estimated, but a few months longer.

Summarising: the ML estimator of the fraction of warranty repairs promises to be a much more informative metric than the WCR, although there are a few practical obstacles.

5 CONCLUSIONS

The statistical information gives information about the overall performance of a product. In contrast to engineering field information, statistical information does not give any details about the failure modes of the product. Statistical information therefore can hardly be used for fast (within the first 3 months) product quality improvements.

However, statistical information gives in the long term an accurate description of the behaviour of a particular product type/generation.

Frequently the industry uses the WCR as a metric for product quality. In this chapter I have demonstrated that the WCR is unable to present the required product quality information soon after product launch. Although the WCR suggests that fluctuations in product quality are made visible, it is useless for this purpose. This has serious consequences for the way companies operate. I mention two of them:

- In order to stimulate people to contribute to product quality improvement, it is common practise to give people a bonus if in the coming year the WCR of a product is reduced with a particular percentage. Because the WCR can hardly be influenced within a timeframe of one year, this bonus system is counterproductive. I have observed that managers decided not to strive for this bonus, because they know that they will not be able to satisfy the criteria anyway, and therefore they prefer to go for the bonus for time-to-market. By neglecting the product quality demands, it is easy to satisfy the time-to-market demands.
- Because of the speed of the field failure information feedback flows, it is quite common that the WCR of a new product seems to be quite good shortly after market launch. By the time the WCR shows the real product quality, it is too late to act.

Theoretically the ML method seems to be capable of giving the right product quality information shortly after product launch. However, there are some practical obstacles that cause that the necessary field information is sent to the manufacturer with a delay of a few months. Further research is necessary to find out whether the field conditions can be improved in such a way that the ML method can be recommended without any restriction.

Design and Implementation of a New Structure for Fast and Reliable Field Feedback

1 INTRODUCTION

This chapter is partially based on [Pet03] and answers research question 3. It deals with the design of a new and fast method that is able to collect the *engineering* information that is vital for product improvement actions before market release. The basic idea (see sections 3 and 4) is that loss of information and waste of valuable time can be avoided in the following way:

- Use a direct information exchange between the customer and the development department.
- Start a consumer tests as soon as a pilot series of products has been manufactured.
- Choose the ‘customer’ in such a way that the most relevant product problems, reliability problems as well as lack of satisfiers, are most likely detected in a sufficiently short amount of time.

In section 2 the new design is developed. It is based on the weaknesses of the present information exchange process.

In section 3 a case is presented in which a new and innovative product could be improved considerable even before the market introduction of the product. This proves that the new design is very promising.

Finally, the main conclusions of the chapter are summarised.

2 DESIGNING A FAST AND RELIABLE INFORMATION FEEDBACK FLOW

2.1 Present situation

As demonstrated in the previous chapters, service centres are in the best position to collect valuable information about frequencies and root causes of product failures. However, the current goal of a service centre is to repair a product as fast as possible. Quite often a product is repaired by just exchanging one or more modules in order to bring a product back to working condition in the most efficient manner without looking into further details. A service centre is not paid for activities that are focussed on the detection of the root cause of a product failure. Unfortunately this has a number of unpleasant consequences:

- Field feedback from the customer to the manufacturer (quality department) is very limited and hardly suitable for quality/reliability improvement; it focuses on:

- Logistics information like spare parts consumption
- Financial consequences like the repair costs during the warranty period
- Repair centres are therefore not able to contribute to product improvement during product creation (development, production) via other information than spare parts consumption.
- As a consequence field information is, in this structure, limited to the number of spare parts use during the warranty period. This information is statistical of nature (number of repairs, number and type of used spare parts, etc.) and therefore has inadequate detail for product improvement.
- As this thesis has demonstrated, it takes roughly between half a year and a year to get this information back to the manufacturer. Given the high innovation degree this implies that even in a case where this information would be potentially relevant, it comes in too late to be of much use for the development of the next generation of products.
- As a consequence of the current, component-based models, there is no structural approach directed at collecting other types of information such as customer information about usability.

The conclusion is that there is a serious gap between on the one hand the information that, from the point of view of quality and reliability, is needed, and on the other end the logistics and costs oriented information that is generated by the present information systems. The next section discusses the requirements that should be fulfilled by a product quality oriented field feedback process.

2.2 Requirements

From the previous chapters it follows that a method is required that fulfils the following needs:

1. It generates technical root cause information about field failures
2. It generates information about possible gaps between the technical specification of a product and the actual field usability as experienced by the end-user.
3. It generates this information early enough to enable product improvement with respect to unforeseen product flaws before full-scale production.

As the requirements touch on the root cause information and usability as seen by the end-user, the following two questions concerning the contribution of the end are relevant:

- Does the end-user give the right information?
- Does the end-user give the right information fast enough?

With regard to the right information the following three aspects have to be considered:

- Technical aspects (software and hardware) that should be improved. This might be related with different classes of end-users, e.g. inexperienced end-users, or very heavy and experienced end-users. These different classes of end-users may experience different technical problems / failures.
- Also the usability may be different for different groups of users.

- For (some of these groups of-) end-users the user manual may give problems; e.g. it may contain wrong or fuzzy information, or it may be too complex for inexperienced end-users.

2.3 Basic model

Figure 8.1 gives the basic model. For simplicity the slight differences between the product flow and the information flow are not depicted.

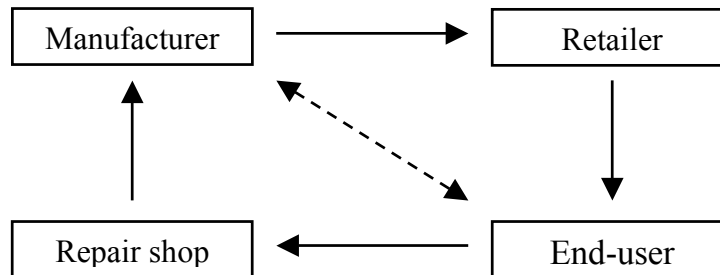


Figure 8.1. Present flow (—————>) and required flow (- - - - ->)

The time span of the information from development via the end-user back to development should correspond with the new product development roadmap. In the previous chapters it has been shown that the product throughput time from manufacturer to end-user is, normally, more than half a year. This explains in figure 8.1 the required (product) flow from manufacturer to end-user. It has also been mentioned before, that information about field failures gets stuck in service centres. This explains in figure 8.1 the required (information) flow from end-user to manufacturer.

The conclusion is that figure 8.1 suggests making a shortcut (dotted line) between the end-user and the manufacturer. It has to be seen whether such a shortcut can be implemented and whether in this way the requirements can be met. This will be discussed in the following sections.

2.4 New design for timely information feedback

Now that the requirements have been set (section 2.2) and the actors have been defined (manufacturer and end-users), a suitable procedure has to be determined. This procedure should be derived from the four requirements:

1. It generates root cause information about field failures
2. It generates information about usability as seen by the end-user.
3. It generates the required information early enough to enable product recovery/improvement with respect to unforeseen product flaws before full-scale production.
4. It generates speedy feedback to 'correct' product/production problems once full production has started.

Approach

From the third requirement it can be concluded that the relevant information has to be derived from products that are not yet on the market. As manufacturers usually produce a test series before they start full-scale production, part of such a test series can be used for early feedback. In order to generate the required information in time, these products should be immediately handed over to a suitable group of test people. This leads to the question: how to design an experiment that is able to satisfy the first two requirements?

These considerations lead to the following structure:

1. What is the purpose of the test? The following classification may be useful:
 - Market uncertainty: customer requirements versus functional specifications.
For example: the required functionality, ease of use, compatibility with other equipment, time to failure, ...
 - Technical uncertainty: functional specifications versus technical specifications.
For example: which characteristics of end-users influence the product failure behaviour? (Frequency of use, use of particular functionality, experience, ...)
 - Industrial uncertainty: technical specifications versus realised product.
For example: is the production process able to perform as required, workmanship?
2. Who should be involved in the test? For example: development, marketing, quality department, production, ...
3. What are the relevant criteria?
 - The relative importance of the three types of uncertainty determines on what characteristics the test group should give feedback. For example: ease of use, functionality, failure behaviour, ...
3. What is the best test design?
 - Should every test person get his own test product, or is it better to use only a few products and have them tested by many people? For example: if the product functionality is the point of interest, then usually different people can test the same product (but at different times).
 - Is it expected that the test will give useful results within an acceptable amount of time, using a realistic number of test products and test people? For example: if a phenomenon is expected to occur one per mil, it will most likely not occur in a sample of 50 products.
 - Does it make sense to divide the test group into more homogeneous subclasses? If yes, what are the relevant characteristics of those subclasses, and how many subclasses are relevant? For example: experience, age, ...

- How many people are required in each subclass? For example: testing whether differences between subclasses are statistically significant requires a suitable number of participants, depending on the variability.
 - What preparations do the members of the different subclasses need? For example: information about the purpose of the test, information about the product, information about the way to report, ...
 - What is the best way to organise the feedback process? For example: by phone, by email, should the members of the test group take the initiative, ...
4. How should the results be analysed and by whom?
- How should the feedback be analysed? For example: on warranty costs, for the technical root cause analysis of each product failure, for the consequences for sales.
 - Who should be involved in the analysis of the feedback? For example: an engineer, a statistician, a marketer, a salesman, ...
5. Who are involved in the decision process that should define the required actions?
- On what criteria should the decisions be based whether or not to improve the product? For example: warranty costs, cost of redesign, reputation, market share, ...
 - Who should be involved in that decision process? For example: the quality department, development, production, marketing, sales, ...

All these questions together should answer an important overall question: is such a test suitable for the product at hand? It all boils down to a simple question: is it likely that a small test group will be able to find relevant improvement points within a time span of a limited number of weeks? If the answer is positive, then the next question is: and will the manufacturer be able to solve all relevant problems within the required time to market?

In order to be able to find out whether there is a relation between the type of use and the occurrence of problems, it is important to register the way the test group uses the product from the very start of the test. Preferably this registration process should be automated by building in a black box with the right functionality. The black box should be able to measure all relevant aspects of customer use.

The results of the test group are not automatically in line with the problems that will be found later by the real end-users that buy their product in a shop. For this reason, it is important to check the results of the experiment after market launch with real field data. This is in particular relevant if a company introduces this test method for the first time and does not have any experience with choosing the participants.

There are two aspects that make a test along the above lines attractive:

- The test can start as soon as the first preproduction run has been produced (the combination software-hardware can only be fully tested when both parts are available).

- Because of the increasing amount of software in consumer products, more and more field problems will be software related. (Recent problems in automobile industry with a top model of BMW prove this decisively). The positive side of an early test is that even in case the market launch starts before the end of the test, new versions of the software can be flashed into already finished but not yet sold hardware. In principle it is even possible to distribute new software via the Internet. In this way the customer can improve products that have already been sold, almost without any costs for the manufacturer; this also saves money by preventing warranty costs.

To close, I make two remarks:

- In order to be able to detect the root cause of a technical problem it might be necessary to visit the end-user to verify the local situation. This should be taken into consideration when the test is planned, in particular in case the product at hand is part of a larger system.
- When a company introduces this test strategy, the first test is not necessarily set up and executed in the best possible way. It will take some time before all aspects are under control. This is an important argument to verify the findings of the test group as far as possible with real field results.

The next section presents a case in which the approach is applied during the development and introduction of a new innovative product: a CD recorder with MP3 functionality.

3 FIELD TEST

3.1 Background

The method has been applied in a real life situation when company High-Volume introduced an innovative new CD recorder with mp3 functionality. The manufacturer expected that the hardware would not give any serious problems, because the hardware was basically equal to the hardware of a previous generation of CD recorders. The manufacturer was not so sure about some software aspects. For example, the manufacturer realised that the software for mp3 playback was relatively slow, and he wondered whether this would annoy the end-user.

It was decided to start an experiment along the lines of the previous section. Planning this experiment required a series of steps [Dum93]:

- Defining the goals and concerns that are driving the test
- Deciding who should participate
- Recruiting participants
- Preparing the test team
- Organising the logistics and information channels (telephone line, e-mail address, ...)

- Preparing the paperwork (contracts, instructions, surveys)

All these aspects were written down in a test plan.

The manufacturer was willing to make 100 devices from a trial run available for the experiment. Because of the fact that different people use the device in a different way and consequently might end up with different problems, it was decided to use a test group of 100 people and to give each person his own device. Unfortunately it was not possible to analyse the relation between customer use and product failure behaviour, because by a misunderstanding the 100 devices were not equipped with a black box.

The manufacturer is situated outside of the Netherlands; therefore the logistics and information channels were handled in the following way. Three students from the Eindhoven University of Technology (TU/e) were trained to handle the reactions from the test group and to discuss these reactions with a team consisting of representatives from the quality department, development and production. These students worked under the supervision of the quality manager and were physically situated in the quality department. These three students were also trained to handle real customer complaints from the market after commercial release of the product.

During the test there were three software updates that were mainly based on the problems that were reported by the test group. After each update the test group was explicitly requested to check whether the changes were experienced as improvements. The test group was not informed about the specific aspects that had been improved.

In the next section the relation between the aim of the test and the composition of the test group is given. In section 3.4 the corresponding hypotheses are formulated. Finally, in section 3.5 the results of the test are presented.

3.2 The test group

The aim of the experiment was to find improvement points, hoping that improvements could be realised before market release. The weak points of the product were expected to be software issues in relation to the functionality and usability. As explained before, it was expected that the hardware would be quite satisfying.

According to High-Volume the target customer group consisted of people of about 50 years and older with a higher education. High-Volume's quality manager was of the opinion that the older non-technical staff of the Eindhoven University of Technology was very similar to the target group. He also expected that technically inexperienced users would come up with other remarks / suggestions / problems than technically experienced users, and that young people would use the product more intensely than older people, in particular the MP3 functionality. Moreover, it was expected that people with a technical background would be more interested in the experiment and would therefore cooperate more intensely.

This led to the decision to concentrate the test on the employees and students of the Eindhoven University of Technology. An additional advantage of this group was the easy communication.

In order to balance the experiment as much as possible within the boundary conditions, it was decided to distribute the 100 test people over two age classes and two different

backgrounds. In order to increase the likelihood of finding differences between the groups, it was decided to use high contrasts, that is: the groups were made as different as possible on the criteria age and (technical) background. This led to the definition of the four test groups as given in table 8.1.

Table 8.1. Composition of the test group, 25 people in each group.

Background	Students	Staff
Non-technical	25	25
Technical	25	25

As mentioned before, it was expected that the group of non-technical staff was quite similar to the target group. The students that are called ‘non-technical’ are students from the faculty Technology Management, and the non-technical staff was selected out of the non-technical staff of the faculty Technology Management. The technical students and the technical staff were selected from the Mechanical and Electrical engineering departments. All students were younger than 24 years of age. The staff was almost exclusively of age 45 and older.

The participants had to sign a contract in which among others was stated that:

- They got the device for free.
- They would never sell the device, nor bring it to a service centre for repair.
- They would inform the manufacturer immediately about any problem or inconvenience they experienced with the device (using a special university e-mail account).

3.3 Test hypotheses

As discussed implicitly in the previous section, the composition of the test groups was geared to the following relevant hypotheses that were on test:

- Hypothesis 1: The test group reports at least the same problem types as the real end-user. This hypothesis was the basis for the whole test.
- Hypothesis 2: using a test group during the last phase of the PCP increases the speed of the feedback compared with real field feedback that is collected via the regular service facilities.
- Hypothesis 3: people with a technical background report problems faster than people with a non-technical background.
- Hypothesis 4: technical people report more problems than non-technical people. (It was expected that people with a technical background would actively try to find the boundaries of the design.)
- Hypothesis 5: younger people report more problems than older people. (It was expected that younger people would test more thoroughly all the functionality of the device, in particular technical younger people.)

- Hypothesis 6: the non-technical staff represents the real customer. This was the expectation of the manufacturer.

In the beginning the manufacturer was of the opinion that all 100 devices should be given to the potential target group; but he could be convinced that the test should be seen as a kind of accelerated field test. Acceleration had to be introduced by choosing people who would test the device more intensely than the target group.

Other relevant research questions were:

- Are the reported problems almost exclusively software problems?
- How long does it take to fix serious problems? In other words: can the test be used to improve the device before market launch?

In the next section the results of the analyses are presented.

3.4 Results

Because of confidentiality reasons I will not report in detail but stick to the main points.

Hypothesis 1: a test group reports the same problems as the real end-user

The facts are the following. The first field feedback from the real end-user came in 20 weeks after production start. The first 84 devices that were sent back to the company resulted in 15 different failures, while the test delivered 29 different failures. The real customer reported 9 failures that were not reported by the test group, seven of these failures were hardware problems. The test group reported only 2 hardware problems. The results are summarised in table 8.2.

Table 8.2. Distribution of reported hardware and software problems that have been recognised by the company

	Customers only	Test group only	By both groups
Hardware	7	1	1
Software	2	22	5

Given the number of devices in the field and the number of devices in the test, the result is not surprising. It is in line with the expectation that most problems would be software problems.

It will be clear that these differences are highly statistically significant. (A chi-square test for testing whether the distribution of the reported problems over hardware and software is the same for the group customers as for the test group gives a P-value of 0.002).

Summarising, the following two conclusions can be drawn:

- The test group comes across less hardware problems than the real customers; this is not surprising given the limited number of products in the test group.

- The test group reports considerably more software problems than the real customers; most of these software problems concern the usability.

Hypothesis 2: using a test group increases the speed of the feedback

This hypothesis has been proven very convincingly:

- The first emails from the test group arrived the same day the test devices were distributed (10 days after production); and after 9 weeks 90 % of all different reported failures were reported.
- The first field feedback from the real customers came in not before 20 weeks after production start.

Hypothesis 3: people with a technical background report problems faster than people with a non-technical background

Of all 11 failures that were reported by the older people as well as by the younger people, the older people reported 7 failures earlier than younger people, but the differences in calendar time are that small that from a practical point of view this result is not interesting. Furthermore, also from a statistical point of view the hypothesis has to be rejected.

Hypothesis 4: technical people report more problems than non-technical people

This hypothesis has to be rejected. Looking at the plain numbers the technical people reported 21 different problems and the non-technical people 19.

Hypothesis 5: younger people report more problems than older people

This hypothesis has to be rejected. Looking at the plain numbers the older people reported 22 different problems and the younger people 16. This difference might be practically relevant to the manufacturer, but because of the limited number of participants the difference is not statistically significant.

The best test group was the older technical group, see table 8.3. This group reported statistically significant (one-sided P-value is 0.03¹) more problems (17) than the other groups (who reported 10, 10 and 9 different problems).

Table 8.3 Distribution of the number of reported problems within the test group

	Technical background	No technical background
Older people	17	10
Younger people	10	9

¹ The uniformly most powerful unbiased test was used [Leh59, p. 143].

Remark. The older technical group reported 17 different problems; the older non-technical group reported 10 different problems. Together this resulted, because of some overlap, in 22 different problems for the total group of older people. Analogously, the younger technical people reported 9 different problems, the younger non-technical group reported 10 different problems. Together this resulted in 16 different problems for the total group of younger people.

Hypothesis 6: the non-technical staff represents the real customer

This hypothesis has to be rejected. One of the major differences between real customers and the test group is that the test group reports a lot of problems that are related with things they do not like, like slow mp3 functionality. The real customers did not report this kind of problems. From this point of view there is a major difference between the non-technical staff and the real customer. This alone could be a strong argument to make use of this type of tests, because most likely the real customer does not like these same aspects either.

Finally I will discuss the last two research questions that were posed in the previous section.

Are the by the test group reported problems almost exclusively software problems? This question has already been answered while discussing hypothesis 1. The answer is affirmative. This may have been caused by the fact that the hardware part of product had already been tested in previous generations, and therefore has a high reliability.

How long does it take to fix serious problems? In other words: can the test be used to improve the device before market launch? As the test worked out to concentrate on software problems, the answer is a cautious YES. About 90% of all reported failures were reported within 9 weeks after the start of the experiment (the experiment was terminated after six months), while the market launch was three months after the start of the experiment. During these three months it was possible to correct many but not all software problems. For cost reasons the manufacturer deliberately decided not to correct some software weaknesses that were related with the basic structure of the software. I have no details about how many software weaknesses exactly have been corrected before the market launch.

One of the important results of the experiment was the fact that during the test the manufacturer was able to cover many customer complaints about the software via two software updates.

Given the delay between the production of the hardware and the sale of the devices to the end-users, it is in principle possible to supply the end-user with an updated version of the software. The dealer can arrange this update before as well as after sales. Another possibility is to make software updates available via Internet.

4 CONCLUSIONS

The research question that is at stake in this chapter reads:

Can the test be used to improve the device before market launch?

The answer is a conditional yes. The following arguments clarify this statement:

- The results of the test group were available about half a year earlier than the regular field results using the standard procedure.
- The test generated all software problems that were reported by real customers, but not all hardware problems.
- The majority of the problems found during the test could be solved before full-scale market introduction.
- The older technical staff reported a significantly greater variety of problems than the other test groups.
- It was not possible to correct all software problems before the market launch, partly because of deliberate decisions by the manufacturer to postpone improvements to a later generation, partly because of the relatively short duration of the experiment, and partly because it was too complicated to correct the software.
- In case customer satisfaction is seriously related to the quality of the software, it is possible to produce and ship the hardware to the retailer, while the retailer loads the latest version of the software at the moment the customer buys the product.
- It is technically possible to distribute the latest version of the software via the Internet. In this way the end-user can update the software.

The final conclusion of the manufacturer of CD recorder that was used in the test is: from now on a test like the one described will be executed for every innovative new product for which the technical behaviour in the hands of the customer is rather uncertain.

Referring to section 2.4 the system fulfils all four requirements:

1. It generates root cause information about field failures
2. It generates information about usability as seen by the end-user.
3. It generates the required information early enough to enable product recovery/improvement with respect to unforeseen product flaws before full-scale production.
4. It generates speedy feedback to 'correct' product/production problems once full production has started

Conclusions and recommendations for further research

1 INTRODUCTION

This chapter is organised as follows. In section 2 the major research findings are summarised with respect to the research problem and the three research questions identified in Chapter 3. Recommendations for further research are given in Section 3.

2 CONCLUSIONS

In this thesis the field feedback process in consumer electronics industry have been analysed. This research only deals with fast PCPs under time to market pressure.

The conclusions are summarised below.

2.1 Problem identification

During the first phase, relevant literature was studied in order to be able to determine the research focus. At the end three research problems were formulated. The major findings are listed below.

Market trends (chapters 2 & 4)

In consumer electronics companies are confronted with a number of trends:

- Increasing customer demands with respect to functionality and product quality/reliability
- PCPs in high-volume consumer electronics are dominated by strong pressure on time to market. Being first in the market gives a company the opportunity to set the standard and to secure a larger market share with increased product revenues from the extended sales life.
- In their effort to be on the market as fast as possible, there is not enough calendar time available for a thorough test programme. This is a threat for the product quality and reliability: immature products may be put on the market.
- Increasing product complexity makes it more and more difficult to predict how a product will behave when in use.

Required: quality prediction methods

In order to assure the right quality and reliability of products, companies should anticipate the problems that appear as a result of the market trends. This requires prediction methods that take these trends into account. The most common prediction model is based on a constant failure rate. Literature makes clear that the constant

failure rate model that only takes into account component reliability is not valid for the present complex consumer electronics products. (cf. chapter 2 section 2)

This leads to the need of a new prediction model, but in order to be able to build such a model, more information about the field failure behaviour of products is required. Chapter 2 proves that the information loop from the customer back to the manufacturer is not suitable for product reliability improvement. It is explained that a correct prediction can only be made when the right information is available, at the right time and at right place.

As a result of the preliminary research, the following three research questions were formulated:

- Research question 1: What field failures information is vital for product development?
- Research question 2: What field failures information do companies collect?
- Research question 3: What activities can be performed to close the gap between needed and available field failures information, taking into account the timeliness of the information?

In the following sections for each of the three research questions the conclusions are discussed. Just as in the previous chapters, these discussions make a distinction between engineering and statistical field information.

2.2 Research question 1: What field failures information is vital for product development?

- Engineering field information (chapters 2 and 6)

Engineering information is used in order to discover the root causes of failures as fast as possible and to be able to improve the product. This information is in particular tailored to the operational level: engineers. In general it can be stated that for quality improvement activities technical information about product root causes is much more important than statistical information about number of failures. In particular, technical information about an individual product failure might be used for product quality improvement activities, while statistical information is only valuable when enough information has been collected.

Because the failure behaviour of a product depends on more than just components (figure 2.2), the engineering information should cover more aspects, like

- Information about the customer set-up
- The sequence of actions that led to the failure

In general it should be taken into consideration that the location where the failure manifests itself, is not necessarily the location of the root cause.

- Statistical field information (chapter 7)

Statistical information can be used in order to evaluate the performance of a product in comparison with standards or other products. This information is in particular geared to the strategic level. Statistical information basically gives a review of the *frequency*

of the field problems. It is in particular relevant on management level for aspects like the following:

- Checking the overall product quality
- Finding trends in product quality
- Predicting financial consequences of product quality/reliability, like warranty costs

A major disadvantage of the use of statistical field failure information is that it is rather slow compared with engineering information. For example, if after product launch the first product failure is reported, then this does not give any indication about the seriousness of the failure. Consequently, it gives hardly any information about the consequences for the warranty costs. Using statistical field failure information, one has to wait until quite some failure data is available before a reliable prediction of the related warranty costs can be given. A root cause analysis, however, has the potential to detect immediately whether the failure is an incident, or a forerunner of a catastrophe.

It has to be mentioned that lifetime considerations should be based on the real failure mechanism, and that is not necessarily related with calendar time.

As can be seen in the following section, the collection of essential product quality information is not common practice.

2.3 Research question 2: What field failures information do companies collect?

In order to answer the second research question, two case studies were performed. For each study the reliability related information flows were analysed from the point of view of engineering information as well as of statistical information.

- Engineering field information (chapter 6)

The following conclusions are based on the two case studies:

- Not all potential sources of engineering field information really generate reliability related information.
- The collected field information is incomplete and not root-cause related.
- Information about the customer experience is not normally collected.
- It takes more than half a year after production start, before information about field failures is available in Development.
- A root cause analysis is difficult, because of the fact that service centres do not collect root cause information, and there is no direct contact between the end-user and the people with the required technical knowledge about the product: Development.

From these points it can be concluded that the available field failure information it hardly useful for product improvement, because it is not available, or incomplete, and anyhow too late.

- Statistical field information

Statistical field information concerns the overall performance of a product in terms of number of repairs, number of spare parts used, warranty costs, etc. Statistical information gives, in the long term, an accurate description of the behaviour of a particular product type/generation. It is relevant to indicate product quality/reliability changes over time. Statistical information is not detailed enough, however, for product quality improvement.

Chapter 7 discusses metrics that are in use in industry to measure the product quality in the field. The focus is on a frequently used metric: the Warranty Call Rate. In chapter 7 it is demonstrated that the WCR is unable to present the required product quality information soon after product launch. Contrary to the belief in industry, the WCR is unable to measure adequately the fluctuations in product quality over time.

A more promising metric is the Maximum Likelihood estimator of the fraction product failures within the warranty period. This metric seems to be capable of giving the right product quality information shortly after product launch. However, more research is necessary, because a serious obstacle is the fact that the required field information is sent to the manufacturer with a delay of a few months. It is not yet clear whether the field conditions can be improved in such a way that the ML method can be recommended without any restriction.

2.4 Research question 3: What activities can be performed to close the gap between needed and available field failures information?

In order to be able to answer this question a test with 100 people and 100 CD recorders was carried out. The most relevant conclusions are the following:

- The results of the test group were available about half a year earlier than the regular field results using the standard procedure.
- The test generated all software problems that were reported by real customers, but not all hardware problems.
- The majority of the problems found during the test could be solved before full-scale market introduction.
- Consistent with the expectation (because the hardware was basically equal to the hardware of a previous CD recorder) almost all reported problems concerned the software.
- The elder technical staff reported significantly more different problems than each of the other groups.
- In case customer satisfaction is seriously related with the quality of the software, it is possible to produce and ship the hardware to the retailer while the retailer loads the latest version of the software at the moment the customer buys the product.
- It is technically possible to distribute the latest version of the software via the Internet. In this way the end-user can update the software himself.

The final conclusion of the manufacturer of the CD recorder is that from now on a test like the one described will be executed for every innovative new product

2.5 General conclusion

Given the fact that field feedback is too incomplete to be useful for product quality/reliability improvement, and is too late anyway, new information collection procedures like the field test procedure (chapter 8) should be studied.

3 RECOMMENDATIONS FOR FURTHER RESEARCH

This research was conducted in the framework of a PhD project, but does not end with this PhD thesis. In the following sections, potential future research directions are discussed.

3.1 Can the results be generalised to a broader range of companies?

This research concentrated on consumer electronics industry with its characteristics: short time to market (short PCPs), increasing warranty time, and increasing rate of non-component related failures, globalisation and segmentation of the business process. The conclusions of my research are only valid for companies with similar characteristics.

An interesting research topic is the role of field information for product quality improvements in different kinds of companies. Automotive industry, for example, has different characteristics, not in the least because a car is a repairable system. It makes sense to study the differences and the similarities between the market trends in the world of automotive and in the world of consumer electronics, having in mind the following questions:

- What is from the perspective of product quality and reliability the value of field information in automotive industry?
- How to collect and analyse the required information given the relatively long warranty period in automotive industry and the fact that cars need regular maintenance?
- Does a field experiment during the design phase make sense, and if yes, how should such an experiment be performed in automotive industry?

3.2 What is the optimal moment within a PCP to perform a field test?

This research studied the reliability problems reported by the field test group based on experience with a finished product. The field test has proven to be able to speed up considerably the reliability related information flow based on real customer experience. While this can be considered as a success in the race with time, still a big volume of products is already on the market before valuable info can be used for product quality improvement.

Table 5.1 shows that the costs of design changes increase dramatically in later stages of the PCP. This suggests that performing similar tests earlier within the PCP is attractive. This leads to two questions:

- What is the earliest moment for a field test if real products are required?
- Are there other ways to generate the required information before real products are available? For example using prototypes, or simulation?

3.3 Which criteria determine the composition of the test group and should these groups be constant in time?

The aim of the experiment was to use field feedback information in order to find product improvement points, hoping that improvements could be realised before market release. The expectation was that technically inexperienced users would come up with other remarks / suggestions / problems than technically experienced users; and that younger people would use the product in a different way than elder people, what might lead to a different failure behaviour as well. Therefore it was decided to balance the experiment as much as possible, by using a test group consisting of 50 technically experienced and 50 technically inexperienced people, and 50 young (below 25 years old) and 50 elder (above 45 years old). One of these four groups was supposed to be quite similar to the target group (see chapter 8 table 1).

The composition of the test group was based on the feeling of the manufacturer, combined with some general statistical principles. Further research about the way test groups should be chosen is absolutely necessary, in particular because in the literature I could not find specific information about it. Such a research should answer the following question:

- What is the relation between the composition of the test group and the aim of the field test?

The relevance of this question can be demonstrated by mentioning that the manufacturer had a strong preference for using only members of the target group.

3.4 How to combine field information with information that comes available during the PCP?

This thesis concentrates on using field information for product quality improvement. It was concluded that field information is too late for quality improvement on the same product generation, or even on the next one (figure 2.3).

Because of the high innovation degree, information about previous generations of products must always be combined with product development information about the new product. Interesting directions for work in this area are:

- What information should be collected from the field?
- What information should be collected during the development process?
- How can development information and field reliability information be combined (quantitatively and qualitatively)?

Roller coaster curve

Kim Wong [Won88] observed already in 1988 that for electronic products the failure rate curve is better modelled by a four-phase roller coaster curve than by a three-phase bathtub curve. The four phases of this roller coaster curve can be described in the following manner [Luy000] using four different classes of defects¹:

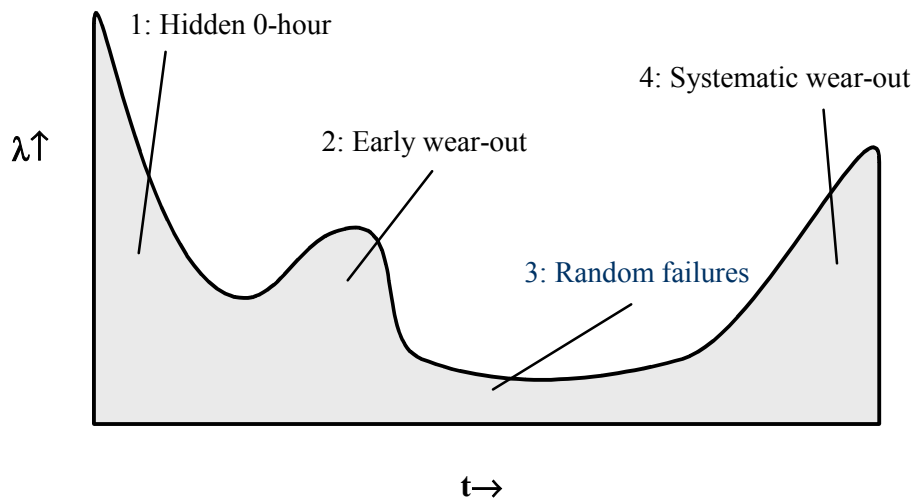


Figure 1. *Four-phase roller coaster curve*

1. **Hidden 0-hour failures:** Sub-populations of products not meeting with customer requirements at $t=0$. The time-delay between the moment of occurrence of failure and the moment of observation / reporting of the failure determines the shape of the curve. Reasons for failures at $t=0$ can be products outside specification (failed products) that reach the customer or products inside the suppliers specification but unacceptable to the customer either due to an incomplete specification or a different perception of the product by the customer.
2. **Early wear-out:** Sub-populations of products operating according to specifications but showing, either due to product tolerances and/or tolerances in customer use, deviating behaviour with respect to degradation. This leads to a

¹ Defective: reported by the user/customer of the product as not working to (implicit or explicit) specifications

situation where such a sub-population of products will be reported defective far earlier than the main population.

3. ***Random failures***: Defects, induced by random events, either internally in the product or in externally from customer use or other external influences.
4. ***Systematic wear-out***: Defects initiated by failure mechanisms in products that lead to systematic degradation of the main population as function of time and/or product use.

Appendix 2

Bathtub curve

For a long time the standard reliability prediction model was based on the use of the so-called bathtub curve. [Erl62] [Lew96]. The bathtub reliability model consists of three phases:

- Phase 1: early failures due to immature products / manufacturing processes
- Phase 2: mature products during useful life
- Phase 3: degraded products due to end-of-life wear out

This model leads to the following strategy for managing reliability:

- Failures in phase 1 are not tolerated and are eliminated by rigorous test programs
- Failures in phase 3 are eliminated by replacement of older equipment by new ones

This leaves only the second phase. As the failure rate is supposed to be constant in this phase, reliability prediction models are relatively easy.

The bathtub model is also very convenient if the product reliability has to be predicted using the failure rates of the components. If it is supposed that all components of a product have a constant failure rate and mutually independent failure times, then the whole product has a constant failure time.

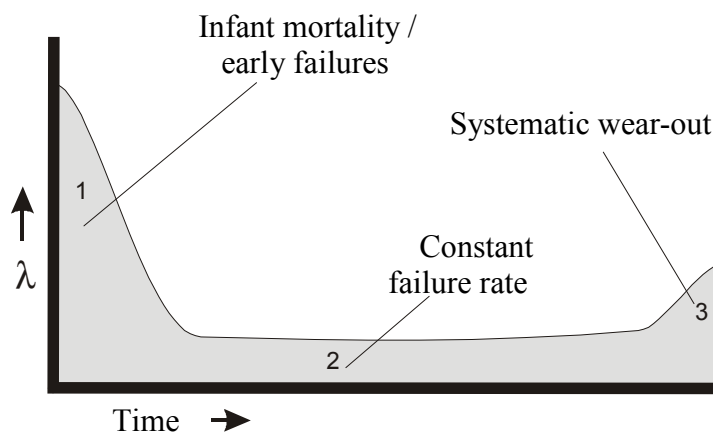


Figure 1 The classical bathtub curve

Appendix 3

IRIS code

In order to get a warranty claim approved the dealer or workshop has to fill in the IRIS (International Repair Information System) repair codes. The IRIS coding consist of two areas:

- The symptom area describes the set's malfunction as perceived by the user. It requires no specific technical know-how to be filled in, and it uses the *condition* and *symptom* code.
- The diagnosis area is intended for the technician to describe where the fault was located, and the actions that were taken by him to repair the product. It uses the *section* code, *part references*, *defect* codes, *repair* codes and a *repair flag*.

Example of IRIS code

Country	Type	Code	Rep date	Sales date	Prod date	Sales to dealer	Condition	Symptom	Section	Part ref	Position	Defect	Repair	Flag	Item id	Quantity
D 106	2526	3769310	17-06-99	16-04-99	11-01-99	19-01-99	ABC 1750			0					0	0
D 106	2526	3769321	01-06-99	09-04-99	11-01-99	12-01-99	BRE 1749			96	MODUL				0	1
D 106	2526	3769321	01-06-99	09-04-99	11-01-99	12-01-99	BDE 1749			40	MODUL				0	1
D 106	2526	3808925	11-06-99	03-05-99	29-01-99	05-01-99	ABC 1750			0					0	0
D 105	2526	4116613	06-07-00	02-10-99	26-08-99	13-09-99	DD 03229	1523	XXX	0		4	Y	1	896200	1
GB105	2527	4021146	04-01-00	20-09-99	17-06-99	25-06-99	DD 02350			0					0	0
GB105	2527	4304176	21-12-99	21-02-00	24-11-99	26-11-99	DD 02349			0					0	0
B 105	2561	3753823	06-09-99	04-04-99	04-01-99	07-01-99	DD 01641	2550	DDM	96	MODUL	J	A	1	8420225	1
N 105	2561	3753824	25-06-99	13-01-99	04-01-99	05-01-99	CCE 1015	2551	DDM	96	MODUL	J	A	1	8420213	1

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