Eindhoven University of Technology

MASTER

How to improve the applicability of HCCT theory for the detection of hard failures

Schrijnemaekers, Erik H.J.

Award date:
2005

Link to publication

How to improve the applicability of HCCT theory for the detection of hard failures

E.H.J. Schrijnemaekers

TU/e

TRADER

DESIGN
TECHNOLOGY
INSTITUTE

Master Thesis

How to improve the applicability of HCCT theory for the detection of hard failures

Eindhoven, November 2005

Author:

Name: E.H.J. Schrijnemaekers
Student ID: 461720

Supervisors:

1st supervisor: Prof. Dr. Ir. A.C. Brombacher
                   Eindhoven University of technology
                   Faculty Technology Management
                   Section Quality and Reliability Engineering (QRE)

2nd supervisor: Dr. Y. Lu
                   Eindhoven University of technology
                   Faculty Technology Management
                   Section Quality and Reliability Engineering (QRE)

Daily supervisor: Ir. I.M. de Visser
                   Eindhoven University of technology
                   Faculty Technology Management
                   Section Quality and Reliability Engineering (QRE)

TU/e technische universiteit eindhoven

TRADER

DESIGN TECHNOLOGY INSTITUTE

Abstract

Current trends in the high-end consumer electronics industry influence the quality and reliability of products. Pro-active methods are needed to predict product failures early in the product development process. These product failures can be divided in hard failures (specification violations) and soft failures (customer expectation deviancies). A comparison is made between different test methods that are used in the product development to select an appropriate way to improve the High Contrast Consumer Test (HCCT) for the detection of hard failures.

Keywords: High Contrast Consumer Test (HCCT), testing methods, hard failures

Acknowledgements

This thesis reflects the result of my graduation project performed as the final part of my Master of Science degree in Industrial Engineering and Management Science. The project was part of the research that is carried out within the department Quality and Reliability Engineering (QRE) of the faculty of Technology Management at the Eindhoven University of Technology (TU/e).

This research project never would have been accomplished without the support and guidance of my supervisors. First I would like to thank my first supervisor prof. dr. ir. Aarnout Brombacher for his coaching and supervision during the project. Also I would like to thank my second supervisor dr. Lu Yuan for her advice and feedback on the report. A special thanks goes to my daily supervisor ir. Ilse de Visser. Her critical comments and the valuable discussions we had were a big help for me to structure and complete this thesis.

During the research, I was hosted at the Design Technology Institute (DTI). I would like to thank all the DTI-students and employees for their support and pleasant company. Especially the games of table tennis we played turned out to be an ideal environment to discuss the research topics and were a nice distraction from the hard work during the day.

Finally a special word goes out to my family and friends. Thank you for supporting me all the way during my entire study.

Erik Schrijnemaekers
Eindhoven, November 2005

Executive summary

Currently the competition will be more decided in the Product Development Process (PDP), due to four major trends that are dominating the industry [Pet03], [Gra01], [Ulr00]:

- **Increasing complexity**: Due to advances in technology, increasingly complex products are introduced to the market. New functionalities are added to products and there is more integration and interaction between products [Whe92].
- **Globalisation and segmentation**: In every business, the numbers of competitors that are capable to compete at a world-class level have grown. Many companies have factories all over the world. Reasons to perform certain activities at different locations are the technical competence available on a location, or the cost or time advantage of a region. This trend complicates the information flows in the product development process.
- **Pressure on time-to-market**: If a company is not the first one on the market with a new product, or at least with new interesting features, than it is difficult to make profit. Therefore time-to-market has to be reduced. Also because of the rapid technological development there is a strong pressure on the product development process. Products will be outdated if product development takes too long.
- **Increasing customer demands**: Customers have grown more sophisticated and demanding. Increased sophistication means that customers are more sensitive to nuances and differences in a product and are attracted to products that provide solutions to their particular problems and needs. Yet customers expect these solutions in easy-to-use-forms. Companies have extended their warranty periods too, to be more attractive than their competitors [Ber00].

The result of these trends is that companies need to develop more complex products, which are introduced faster to the market and meet increasing customer demands.
Due to the increasing complexity of the products some problems can occur in the field. There are two types of problems that can occur in a product, soft failures and hard failures [Bro05].

- **Hard failures.** These are specification violations; situations where the product is not able to meet both the explicit (technical) product specifications and customer requirements.
- **Soft failures.** These are customer expectations deficiencies; a situation where the product meets with the explicit product specifications, but the customer complains on the (lack of) functionality of the product.

Due to the trends of higher time to market pressure and the increasing customer demands it is important to gather information about the performance of the product as soon as possible. The short time-to-market leads to a difference between the time that is required to develop a product and the time needed to learn about the actual performance of the product in the field. Another problem is that the product requirements are only partially known. When product specifications not meet customer requirements during actual product use, this will result in unanticipated complaints on performance. This leads to an increasing number of No Fault Found failures, which are failures where the cause of the complaint cannot be determined.

Petkova states a number of problems that reduce the quality level of the field feedback information [Pet03]:

- Failure information comes in too late in the product development process to make changes in the product.
- The available information is not complete enough for quality improvement.
- Feedback information goes not always to the right place in the product development process.
- Information is often hidden in a huge amount of data that is difficult to analyse.

Petkova [Pet03] showed that field feedback is not very useful. As the feedback information is needed early in the product development process it is necessary to obtain this feedback information in another way. One way of obtaining this failure information early in the PDP can be executing a consumer test.

The advantage of a consumer test is that possible issues can be detected already during the product development process and subsequently changes can be made to the product. However, most consumer tests are often being conducted under ideal conditions with ideal products in a controlled environment with well defined "target customers" and pre-determined test procedures. In an attempt to make consumer testing more effective, an idea was developed for a new test procedure: the High Contrast Consuming Test (HCCT) [Boe03]. In this test the purpose is to observe critical and extreme customers using extreme products in realistic operating conditions. The assumption is that 'normal' products are not likely to fail at 'normal' customers. Therefore the method is developed to maximize the interaction between the customer and the product in order to provoke more failures. In a relative short period a number of contrast factors of extreme users and extreme products are selected. Extreme customers are customers that are heavy users of the product, or very critical on the functioning of the product. Extreme products can be defines as products that are narrowly functioning within the product specifications.

The HCCT method is designed to maximize the variability in the interaction between customer and product. The focus is on finding soft failures during the unpacking, setup and installation of the product, and not primarily to test a product for compliance with specifications.

Nowadays, digital televisions contain a lot more software. This increase in complex software can lead to more problems in the functioning of the product. Due to the pressure on time-to-market, there is less time available for testing, so it is not possible to remove all faults in the products. This implies that there are still faults in the product when it enters the market. There is a chance that these faults will lead to failures when the product is in use and people will complain. As field feedback information is not available in time, failures have to be found during testing procedures before production starts. To create better insight in the customer-usage and to find existing faults or failures in the product, a consumer test can be carried out. As already described in chapter 2 the HCCT test is a method that is developed to accelerate failures and expose product use issues early in the PDP. However, the method is not designed to test a product for compliance with specifications. The focus is on provoking failures that lead to phase 1 and phase 2 failures of the rollercoaster curve. In the situation of LCD television the increase of software in the products will possibly lead to more software failures. These failures are internal product failures (hard failures) and can be classified as random failures (phase 3 of the rollercoaster curve).

Therefore the main research question for this research is:
How to improve the applicability of the High Contrast Consumer Test (HCCT) for the detection of hard failures?

Subsequently, the goal of this research project is to *give suggestions for improving the applicability of HCCT theory for the detection of hard failures.*

To reach this goal the project is divided in two phases. In the first phase will be examined if hard failures are still a relevant problem within innovative high-end consumer products after market introduction. Therefore an experimental test is executed with an innovative high-end consumer product: *a LCD-television.*

The purpose of the experimental test with the LCD-television was to give an answer to the first research sub-question:

Are there still hard failures to be found in a high-end LCD-television after market introduction?

The television and its functions, sometimes with peripheral equipment, have been used during one week. As a result of the experimental test that has been executed, a considerable number of failures have been found (12 hard failures and 7 soft failures)

In the second phase of this research the existing literature about most commonly used test methods are reviewed and suggestions are given how the HCCT theory can be extended with aspects of other methods to improve HCCT for the detection of hard failures. To give an answer to the main research question, three sub-questions are formulated.
- *How to find hard failures?*
- *What are the strong and/or weak points of HCCT?*
- *What test methods can be applied to improve HCCT's capacity of finding hard failures?*

To answer the first research sub-question a description is given of different types of (pro-active) testing methods that are commonly used nowadays. Through a number of characteristics for each method an overview is given of the ways these methods can contribute to find hard failures.

The test methods that are described are divided in three categories: Hardware tests, software tests and consumer tests.
Hardware test that are used in most product development processes for high-end consumer products are: *Quality Function Deployment (QFD), Failure Mode and Effect Analysis (FMEA), Accelerated Stress Testing (AST)* and *Prototype testing.*
Due to increasing amount of software elements in high-end consumer electronics products, software reliability prediction is necessary. Software testing can be divided into different test phases: U*nit test, Function verification test, System verification test, Performance verification test, Integration test* and B*eta test.*
Consumer tests are used to observe how consumers react on new innovative products and how the product performs under real consumer stresses. Two methods are mentioned: *Usability testing* and *the High Contrast Consumer Test (HCCT).*

The following characteristics are evaluated for each research method:
- Type of failures to find with the method (hard/soft failures)
- Test coverage
- Position of the test in the PDP
- Ability for changes/Impact of changes
- Test type
- Duration of the test
- Test environment
- Type of test persons
- Number of products needed for the test
- Product/customer selection criteria

With the characteristics for each method an overview is made for all the methods (see paragraph 5.4). All the methods that are mentioned can be used for finding hard failures.

For providing an answer to the second research sub-question the strong and weak points of the HCCT method are investigated.
The HCCT method was developed because it was found that the traditional consumer tests were often conducted too rigidly to give useful results [Boe03]. HCCT focuses on the testing of a small number of critical and highly contrasting consumers with product prototypes in a

short amount of time. The selection of these extreme customers is one of the strong points of the method, because for each tested function or product the consumers are selected that will use the product in an extreme way. The extreme consumers will probably find failures in the product earlier than consumers that will use the product in a normal way. Also is expected that with extreme customers more different types of failures can be found, due to unexpected behaviour.

Another strong point is that only a small number of test persons and test products are needed for the test. In other tests the selection of test products and participants are selected in a random way. Due to this random selection the expected failures that will be found during the test will behave according a statistical normal distribution. This means that only the most common failures will show up during the test. The failures that can only be found under extreme situations will probably not be found. The purpose of HCCT is to select the products and participants for the test in such a way that the failures caused in 'extreme' situations also will be found.

From the view of finding hard failures, a disadvantage of the HCCT method is, that it is mainly used to find soft failures during the unpacking, installation, setup and first use of the product.

A strong point of the HCCT method is the use of highly contrasting consumers and products. However, the drawback is that it is not clear how these contrasting customers and products should be selected.

In the overview presented in paragraph 5.4 can be seen that all test methods can be used for finding hard failures. However, for the improvement of HCCT not all test methods are useful. In the first place, the purpose of the HCCT method is to execute the test with real customers. Therefore, the test methods that are qualified for a possible improvement for HCCT are these methods that are also using real customers for its test. Possible methods are: prototype testing (hardware test), beta testing (software test) and usability testing (consumer tests). A drawback of these methods, especially the prototype test and the beta test, is that these test methods are time consuming. With the problem of high-pressure of time-to-market nowadays, it is necessary that the time to execute the test will be as short as possible.

Another disadvantage of these methods is that a large sample of test-products and participants are needed to find all failures in the product. This is caused by the random customer selection of the test participants. Here is the strong point of the HCCT method that testing with only extreme customers and products will reduce the number of test participants and products. The problem is the determination of the right contrast factors for the selection of these extreme customers. For a better understanding of the contrast factors and to improve the test, it is important to know what customers expect from a new product and how they will use the product. Early prediction of customer requirements is therefore necessary. This can be achieved with methods as QFD and FMEA, because these methods can already carried out in the concept phase of the product development process.

Especially the QFD method is suitable for finding critical customer requirements. In the QFD approach is tried to identify what the customer wants or expects of the new product and translate these wants to product specifications. If critical customer requirements are known early, also contrast factors can be defined.

As the focus is on finding hard failures it is important that the (extreme) user that participate in the test will find as much hard failures as possible. Therefore it may be useful to test in a similar way as in the AST approach, which is focussed on finding hard failures only. In the stress tests only certain aspects (stressors) of a product are tested. In the situation of HCCT this can be done by letting the customers test only a specific functions or features of the product. When the extreme customers are selected for a certain product feature or function, their extreme usage may lead to finding more hard failures.

As can be concluded from the answers on the sub-questions, it is not clear how to define the critical contrast factors for the HCCT test. The QFD method can be used for defining critical customer requirements. So with the QFD approach it might be possible to make a better indication of relevant contrast factors.

However these contrast factors need to be chosen in such way that they are contributing to the detection of hard failures. In the case of high-end television relevant factors can be the frequent use of a certain function of the television, like teletext for example, or use of a large number of peripheral equipment. If contrast factors and extreme users are selected for only specific functions or features of a product it may be likely that more failures can be found in that certain area of the product because this function or feature is extended to extreme usage.

Finally an answer is given to the main research question:

How to improve the applicability of HCCT theory for the detection of hard failures?

The conclusion is that improvement for HCCT for the detection of hard failures can be achieved by usage of the QFD approach for the detection of critical customer requirements and better selection of contrast factors for the selection of extreme customers for the test. Also testing of only certain aspects (stressors) of the product by extreme users may improve the detection of hard failures.

Table of contents

List of abbreviations

ASP	After Sales Process
AST	Accelerated Stress Testing
CRT-TV	Cathode Ray Tube Television
DTI	Design Technology Institute
DVD	Digital Versatile Disc
ESI	Embedded Systems Institute
FMEA	Failure Mode and Effect Analysis
FVT	Function Verification Test
HALT	Highly Accelerated Life Testing
HCCT	High Contrast Consumer Test
HDMI	High Definition Multimedia Interface
LCD-TV	Liquid Crystal Display Television
NFF	No Fault Found
PVT	Performance Verification Test
PDP	Product Development Process
QFD	Quality Function Deployment
SRE	Software Reliability Engineering
SVT	System Verification Test
TALC	Technology Adoption Life Cycle
TTM	Time-To-Market
USB	Universal Serial Bus

Chapter 1: Introduction

In this first chapter an introduction is given about the recent trends on the consumer electronics market and the problems companies have to deal with. This will lead to a justification why this project is carried out and what its contribution will be for the research area. In the last paragraph the structure of this report is outlined.

1.1 Trends

To deal with competition most companies mainly concentrated on improving their manufacturing processes in the seventies and eighties. However this is not enough anymore. Currently the competition will be more decided in the Product Development Process (PDP), due to four major trends that are dominating the industry. Those four trends are: *increasing complexity, globalisation and segmentation, pressure on time-to-market* and *increasing customer demands* [Pet03], [Gra01], [Ulr00]:

- **Increasing complexity**: Due to advances in technology, increasingly complex products are introduced to the market. New functionalities are added to products and there is more integration and interaction between products [Whe92].
- **Globalisation and segmentation**: In every business, the numbers of competitors that are capable to compete at a world-class level have grown. Many companies have factories all over the world. Reasons to perform certain activities at different locations are the technical competence available on a location, or the cost or time advantage of a region. This trend complicates the information flows in the product development process.
- **Pressure on time-to-market**: If a company is not the first one on the market with a new product, or at least with new interesting features, than it is difficult to make profit. Therefore time-to-market has to be reduced. Also because of the rapid technological development there is a strong pressure on the product development process. Products will be outdated if product development takes too long.
- **Increasing customer demands**: Customers have grown more sophisticated and demanding. Increased sophistication means that customers are more sensitive to nuances and differences in a product and are attracted to products that provide solutions to their particular problems and needs. Yet customers expect these solutions in easy-to-use-forms. Companies have extended their warranty periods too, to be more attractive than their competitors [Ber00].

The pressure on time-to-market requires a company to reduce the development time of a product to reach the market in time. It is important to be on the market before competitors do. Therefore the product development process needs to as short as possible. Due to this time-to market pressure it is possible that complex products are introduced to the market without being tested rigorously.

Companies are competing with each other to gain the favour of the customer. To gain this favour, companies have to compete at four business drivers to be able to withstand and beat the competition. These four business drivers are [San00], [Luy99]:

- **Functionality**: is the product able to fulfil its intended function.
- **Quality**: does the product fulfil customer requirements at 'all' customers, not only at the moment of purchasing but also during operational life of the product?
- **Time**: does the product reach the market at the required moment in time?
- **Profitability**: the difference between product cost and product sales price.

The four business drivers are in conflict with each other. Manufacturers have to introduce a new product to the market with good quality that satisfies its intended function in a market where high pressure on time-to-market exists. Of these four business drivers, time is the most important business driver. Especially the time-to-market (TTM) is very important for new

products and the profitability of the company. However, when the product is released earlier than the competitors' products, but its quality or functionality is poor, the product will not increase the company's profitability. Also when a product is released too late to the market, compared with the competitors, the manufacturer will not earn a lot of money. It is then too late to sell big quantities and the price erosion lead to that it is even difficult to make a profit on each separate sold product.

There is also an important relation between the position in the product development process (PDP) and the effort that is required for design changes in the PDP. Changes that are made in later phases of the product development process require more effort and are more expensive than changes made in earlier phases. These exponential increasing costs can be seen in table 1.

Table 1: Costs of design changes in the PDP [Bus90]

Phase in PDP where changes are made	Costs
Design	$1000
Design Testing	$10.000
Process Planning	$100.000
Production Testing	$1.000.000
Final Production	$10.000.000

It is necessary to optimize the product, the design as well as the reliability as early as possible in the design phase. But the problem is that field information about the product is not available yet. So it is necessary to use predictive models to realize the early identification and resolution of potential reliability and quality problems.

1.2 Problems

Due to the increasing complexity of the products some problems can occur in the field. A first group of problems are due to physical failures in the product. A second group of failures consist of functional failures; there can be situations where there are no physical failures in the product, but in which the product does not meet customer requirements. Therefore two types of failures are distinguished [Bro05]:

- **Hard failures.** These are specification violations; situations where the product is not able to meet both the explicit (technical) product specifications and customer requirements.
- **Soft failures.** These are customer expectations deficiencies; situations where the product meets with the explicit product specifications, but the customer complains on the (lack of) functionality of the product.

Nowadays, one of the main problems in fast, strongly innovative product development processes is the difference between the time that is required to develop a product and the time needed to learn about the actual product performance in the field. The speed to bring new technology on the market is increasing. This leads to a decreasing development time, but the time required to learn about the field performance of these complex products has not been reduced in an equal way (figure 1-1) [Bro05].

2
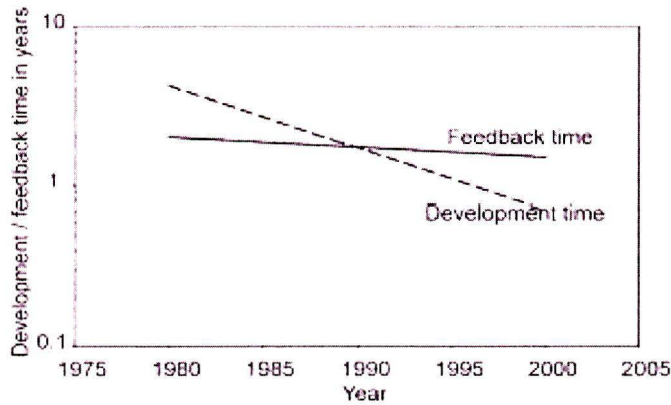
Figure 1-1: Development time vs. feedback time for high-volume consumer electronics [Bro05]

This means that there is an increasing time gap; there is (relative) less time available to gather detailed failure information about the product. The challenge now is to obtain this information earlier. The development of fast feedback systems and accurate prediction methods for use in the design process of strongly innovative products become very important.

Another problem of strongly innovative products is that product requirements are often only partially known. When the anticipated specifications used during the product development process, do not meet with the requirements during actual product use, this will result in unanticipated complaints on performance. This information gap leads to an increasing percentage of 'No Fault Found' failures. These are failures where the cause of a complaint cannot be determined (figure 1-2) [Bro05].
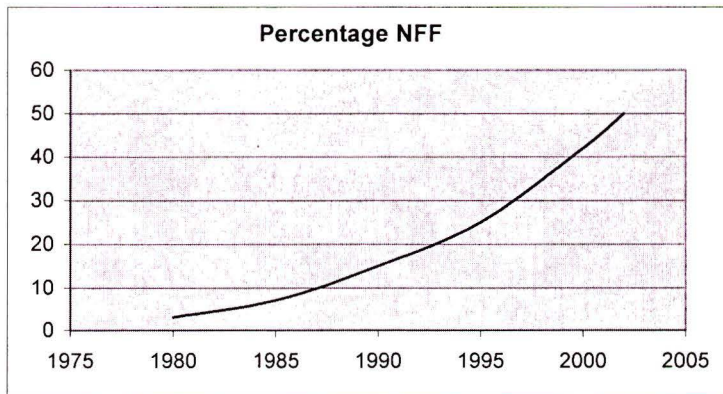
Figure 1-2: Percentage No Fault Found (NFF) [Bro05]

According to Brombacher et al. [Bro05] there are some ways to bridge the above-mentioned gaps:
- The development of fast feedback systems for use in the design process of strongly innovative products.
- The development of dynamic high-resolution analysis systems for the root-cause identification of performance, quality and reliability problems.
- The development of design strategies that stimulate earlier product optimisation by facilitating iterations with respect to performance, quality and reliability problems early in the design process.

1.3 Research

Prediction of reliability is difficult as result of above-mentioned problems. To find solutions for the problems more research is necessary. The research can concentrate on two areas [Gra01].

The first one is the development of accurate prediction methods and techniques. Some prediction methods, like Quality Function Deployment (QFD) or Failure Mode and Effect Analysis (FMEA) are already available. For these models accurate information is necessary. However, prediction models also have to be capable to deal with risks and uncertainty. Lu [Luy02] has shown that these instruments are not capable to deal with uncertain information.

A second way is to develop methods for fast and efficient learning of (unexpected) field problems. 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 the current product, or the very next generation. With the pressure on time-to-market and shorter product development processes, there is not sufficient time to get this information on actual field performance feedback in time [Pet03]. Therefore it is possible that companies deliver immature products to the market. As field feedback is not available in time, the production process should be managed in a proactive way to prevent reliability problems. Proactive means that the information about possible failures needs to be available before the production starts. The research of this thesis concentrates on this last research area.

Due to combinations of new technology, new customers and new structures used in the development process, certain aspects of product quality and reliability can only be found at the customer. To find reliability problems and collect consumer comments early in the product development process a consumer test can be executed. A simulation group of customers, who must represent a group of customers that will buy the product after mass production, will test the product in a so-called High Contrast Consumer Test (HCCT). This type of test is used to identify failures caused by unknown customer use through interactions between extreme products and extreme users. A broader description of the high contrast consumer test is given in chapter 2.

1.4 Trader project

The research that is carried out for this master project is part of a larger project, the *Trader project*, which started in September 2004. The Trader project is carried out under the project management responsibility of the Embedded Systems Institute (ESI). Trader is a collaboration of industrial and academic partners: Philips Semiconductors, Philips Consumer Electronics, Philips Research Laboratories, Philips TASS, Delft University of Technology, Design Technology Institute (a joint research institute of the Eindhoven University of Technology and the National University of Singapore), Twente University, University of Leiden, IMEC, and Embedded Systems Institute [Esi04].

The Trader project considers the area of consumer electronics, and in particular television, as their study and application domain. The objective of the Trader project is to develop methods and tools for ensuring the reliability of consumer electronic products. This should result in minimizing the number of product failures that are exposed to the user. It is unavoidable that there are errors in the products, and within Trader there is searched for ways to cope with these errors over time. The focus within the Trader project is mainly on finding hard failures, failures that violate the technical product specifications.

Also there is searched for ways to understand the psychology of the user (acceptability of failures) and to recognize a system in a faulty state and ways to recover from it. It is important to know what types of defects can occur and how they manifest themselves to the user. Therefore these faults have to be modelled and analyzed on their consequences.

One of the current research projects of Trader is the investigation of the reliability of a LCD-television. For this LCD-television especially the reliability of the software is investigated. The focus is on software, because nowadays this investigation of software failures becomes more important, since in recent development the new generation televisions have more software than several years ago.

1.5 Research focus

The research in this master thesis is focussed on preventing reliability problems in a proactive way. Due to the trends of higher time to market pressure and the increasing customer demands it is important to gather information about the performance of the product as soon as possible. As Petkova [Pet03] showed that field feedback is not very useful, testing of the product before market launch is one of the few useful ways to discover reliability problems. Therefore it is needed to find as many failures as possible during this testing. As mentioned in paragraph 1.2 there are two types of problems that can occur in a product, soft failures and hard failures. In the Trader project the focus is only on dealing with hard failures, especially in the LCD-television domain.

To find these hard failures during testing several methods can be used, like stress tests and software tests. However, these tests give no exact indication of how a product will react during actual customer use. Therefore companies also use consumer tests to observe how customers react to the new innovative products and how the product reacts to the stresses of customer use. A particular consumer test that can be used to provide failures is the High Contrast Consumer Test (HCCT) (see chapter 2)

The main purpose of this research is to provide a way to improve this high contrast consumer test to find hard failures for the LCD-television domain.

1.6 Structure of the report

In this paragraph the structure of the report is presented. Chapter 2 gives an overview of the theory that is used from the existing literature. In Chapter 3 the research methodology is presented. Chapter 4 deals with the testing procedure how to identify failures from the product behaviour and subsequently the failure data that has been found during the testing is discussed. In chapter 5 an analysis is made of different types of test methods. On the basis of some characteristics an overview is made of these methods and characteristics. This is used to evaluate how these methods can contribute to an improvement of HCCT testing to find hard failures and an answer is given to the research questions. Finally in chapter 6 conclusions are drawn about the achieved results. Also some recommendations and suggestions for further research are presented.

Chapter 2: Literature overview

In this chapter an overview is given of definitions and some important concepts for the understanding of this research. The theory in this chapter is derived from the existing literature.

2.1 Quality and reliability

In the product development process a lot of effort has to be focused on the quality of the new product, because quality is one of the four business-drivers. But what is really important for the customer is not only the quality of a product, but especially the reliability of a product. According to definitions from Lewis [Lew96] quality and reliability can be defined as follows:

Quality   Quality is the totality of features and characteristics of a product or service that bears on its ability to satisfy given needs.

Reliability   Reliability is the ability of a product to fulfil its intended purpose for a certain period of time under a given set of conditions.

While reliability is concerned with the performance of a product over its entire lifetime, quality is concerned with the performance of a product at one point in time, usually during the manufacturing process. As stated in the definition, reliability assures that components, equipment and systems function without failure for a desired period; mostly this will be for the whole design life, from introduction to removal.

When a customer is not satisfied with a product he/she bought, there is a mismatch between product performance and the customer requirements about the product. For a customer all instances of such a mismatch will be seen as 'reliability problems', but there can be a large number of different processes leading to such an event.

2.2 Product reliability

Brombacher [Bro05] distinguishes three different 'dimensions' of reliability problems in modern products (figure 2-1):
- Specifications (physical or functional failures)
- The relevance of statistics (failures happening only in certain groups of products or in all products)
- The influence of time (random failures or failures due to accumulation of time or customer use of a product).

The first process relevant to product reliability is the role that specifications play in the life cycle of products. These specifications are supposed to reflect the (intended) product functionality in interaction with the user of the product. A common approach is to assume that a product fails at the moment it does not meet the specifications. There can be many reasons for a failure and therefore the failures are divided in some classes. The following classes can be distinguished [Bro05]:

- *Physical failures.* Many traditional reliability models assume that a product consists of components and that a failure will happen when a gradual or instantaneous change occurs in a component. This is called a component failure. If such a component will fail and some form of redundancy does not cover this failure the entire product will fail [Lew96]. Two types of physical failures exists:
    - o   Wear-, time- or use dependent failures
    - o   Independent (random) failures

- *Functional failures.* Problems where no physical failure in a product exists. But in spite of the absence of physical failures the product does not meet customer requirements. For problems in this class there can be two reasons. Either the product is, for other reasons than physical failures, not able to meet specifications or there is a mismatch between specifications and customer requirements. This leads to the description of two different reliability problems:
  - o **Hard reliability problems:** Specification violations; Situations where the product is not able to meet both the explicit (technical) product specifications and customer requirements.
  - o **Soft reliability problems:** Customer expectation deviancies; Situations where in spite of meeting with the explicit product specifications a customer explicitly complains about the (lack of) functionality of the product.

However, it is almost impossible to fully specify a product. Only for simple mono-functional products the specifications can be fully specified, but for products that are more complex this is not possible anymore. Especially for products where software is involved is it difficult to write a specification that covers all areas of the product [Bro05].

The relevance of statistics relates to differences in users and products that must be taken into account. Some products have different failure characteristics than others, due to different user profiles or product aspects. Some type of users may experience problems with a product and others not. Some failures happen in all products and some only in certain sub-groups.

The influence of time is points to the fact that some failures have a time-independent random character and others only occur after a certain amount of time. The occurrence of some failures after a certain period of time can be caused by a gradual change of behaviour in time or a gradual change in physical properties (drift or degradation). Also different behaviour of customers can lead to failures after some time.

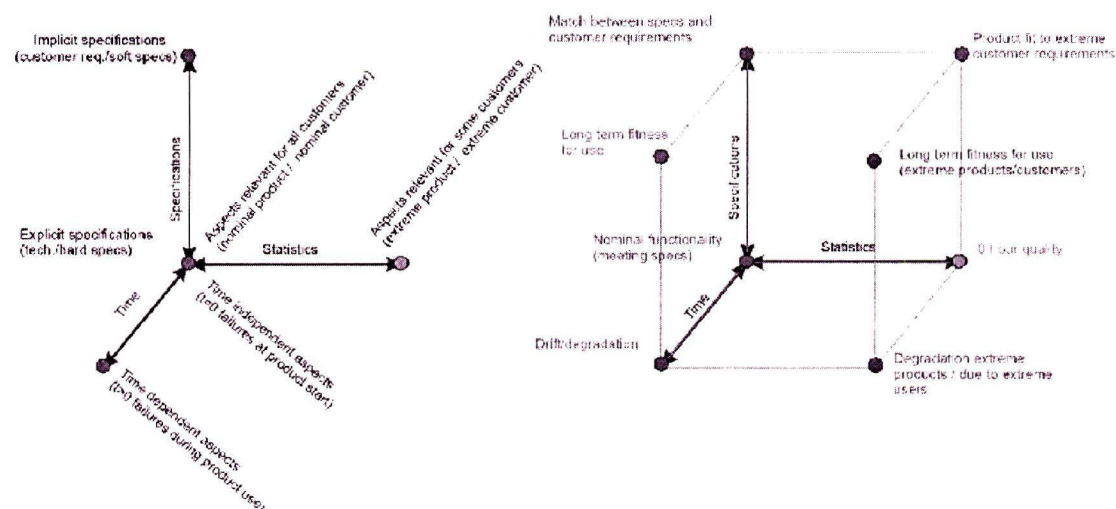**Figure 2-1: Different types of reliability problems [Bro05]**

2.3 Failure rate

Reliability can be defined as a time-dependent concept. To model this time-dependency, the concept failure rate is defined [Lew96]. A practical model to describe these failures over time is the bathtub curve. This model is based on the assumption that product reliability is determined by the reliability of its components.

2.3.1 Bathtub curve

The bathtub curve consists of three broad classes of failures (figure 2-2). The first class is a region of high but decreasing failure rates, the "infant mortality" early life phase. The failure rate is dominated by early failures caused by weaknesses. The failure rate decreases with time as the early failures are repaired and detected. Missing parts, sub-standard material batches, components that are out of tolerance, and damage in shipping are a few of the quality weaknesses that may cause excessive failure rates near the beginning of design life.
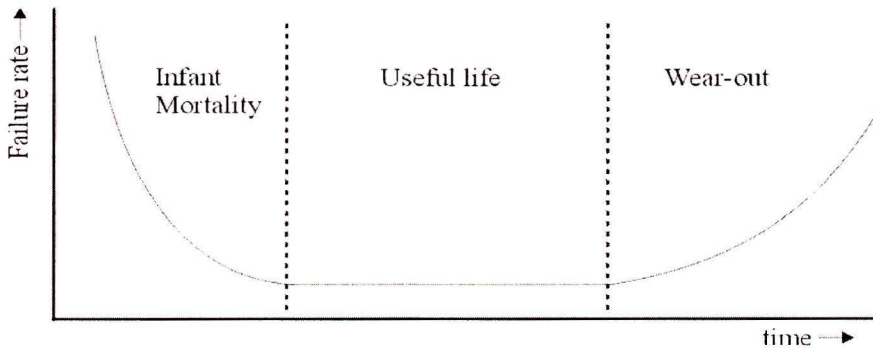
Figure 2-2: Bathtub curve [Lew96]

The middle section of the bathtub curve contains the smallest and nearly constant failure rates and is referred to as the useful life phase. This flat behaviour is characterised by failures caused by random events and hence referred to as random failures. The failures in this section may take a wide variety of forms, depending on the type of system under consideration: earthquakes, power surges, vibration, mechanical impact, temperature fluctuations and moisture variation are some of the common causes.

The last class of the bathtub curve is a region of increasing failure rates, called the wear-out phase. During this period of time aging failures become dominant. The failures tend to be dominated by cumulative effects such as corrosion, fatigue cracking and diffusion of materials. The onset of rapidly increasing failure rates normally forms the basis for determining when parts should be replaced and for specifying the system's design life.

Constant component failure rate models and parts count methods can be used without serious risk in a situation where product reliability is predominantly determined by the reliability behaviour of components and the component reliability models reflect the behaviour of the respective components in the field. But in areas with a high degree of technological innovation the above-mentioned requirements are not fulfilled and for this reason those models are not useful. A roller coaster failure rate has been developed to replace the constant failure rate to model the product behaviour in fields with high degrees of technological innovation [Won88], especially in several branches of the electronics industry.

2.3.2 Roller coaster curve

Research has shown that in several branches of the electronics industry, especially in the areas that have a high degree of technological innovation, the bathtub curve is not suitable for reliability prediction. Therefore, for products with a high degree of technological innovation the roller coaster curve should be used [Won88].

Figure 2-3: Roller coaster curve [Won88]
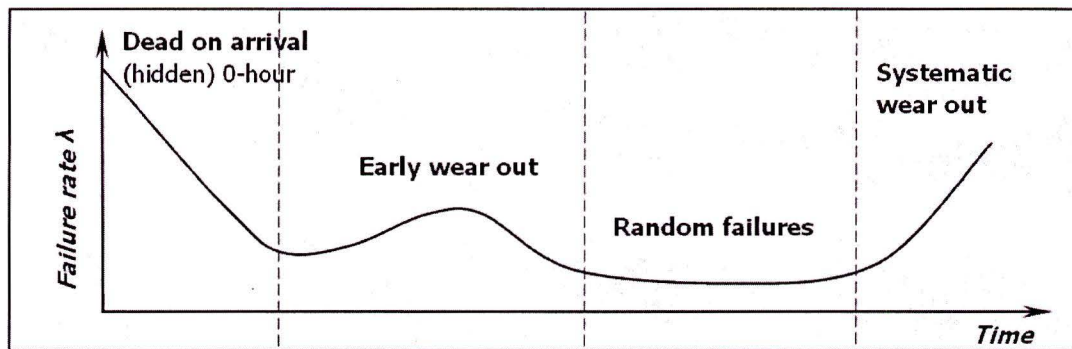
The roller coaster curve (figure 2-3) uses four different classes of failures [Luy00]:

1. **Hidden 0-hour failures**: Products that arrive out of- (customer) specifications at the customer. These products have either slipped through the final tests, have been damaged during transport or are used in an unanticipated manner. Although, theoretically, these failures should all be observed at the moment of release of the product, complex functionality or delay in customer reporting can cause delay in observing and reporting a failure.

2. **Early wear-out**: For high volume consumer products it is not unlikely that there are considerable differences between customers who will use the same product. In some cases this can lead to situations where a distinct sub-population of products, caused by these differences between customers, shows different reliability behaviour than the main population with respect to wear-out. In the failure rate curve these sub-populations can appear as one or more humps.

3. **Random failures**: Products can fail to random events. Products are designed to be used under anticipated (normal) user conditions. It is difficult to anticipate and to design against all events that a product can be subjected. In those cases where the likelihood of occurrence for these events is constant in time and constant over the product population the effect will be a constant failure rate. The failures are internal in the product or external from customer use or other external influences.

4. **Systematic wear-out**: Many products show some form of degradation over time. Or users consider the product as obsolete. At the moment in time where these failures start to dominate the failure rate curve it will lead to an increasing failure rate.

Due to the trend of short time-to-market phases 1 and 2 of the roller coaster curve become more important. Products are introduced earlier to the market, so there is less time to eliminate all the phase 1 and 2 failures during tests. With new innovative products it also can be possible that products never reach phase 3 or 4, because they have already been replaced by newer generations of the product. Phase 1 failures can be both hard reliability problems and soft reliability problems. Phase 2 failures are mainly hard reliability problems, either due to tolerance in design or product or tolerance in customer use. For high volume consumer electronics products phase 1 and phase 2 are most relevant [Luy00]. Complicated business processes, rapid product technology innovation, increasing time-to-market pressure and increasing customer demands also lead to an increasing number of No Fault Found (NFF) failures.

2.4 No Fault Found

The results of a study by Brombacher show [Bro96] that the reliability problems in innovative products can be split up into problems on "Component level", problems on "Internal product level" like interaction problems, and problems on "Customer level". This is visualized in

9

figure 2-4. This analysis showed that the group of "No Fault Found" caused the largest single group of problems. [Bro05]. These No Fault Found failures are failures where the cause of the complaint could not be determined. The complaints are about products that are rejected by customers, but are still functioning within product specifications.
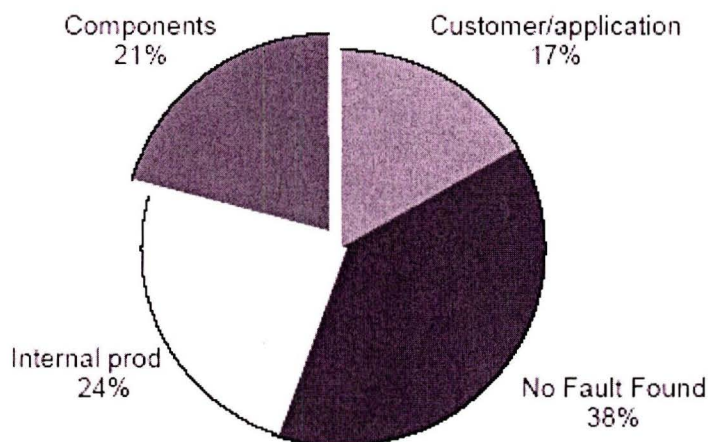
Figure 2-4: Categories of reliability problems [Bro96]

Only 21% of all the reliability problems in innovative products were component related reliability problems (figure 2-4). As a result of this low score, it is legitimate to replace the bathtub curve with the roller coaster failure rate curve in areas with a high degree of technological innovation.
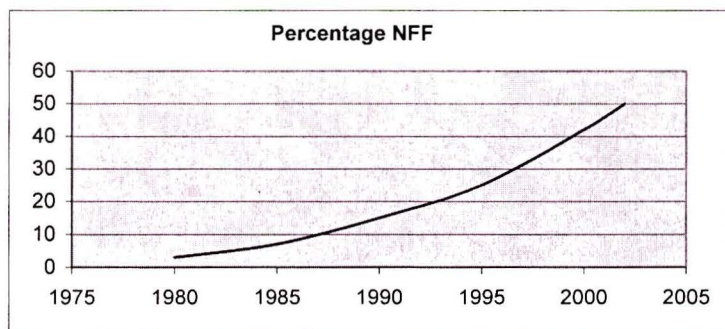
Figure 2-5: Percentage No Fault Found (NFF) [Bro05]

As seen in figures 2.4 and 2-5 the category "No Fault Found" becomes increasingly more important and the reliability problem rate of NFF-curve is increasing. A reason for this increasing curve is that the development of innovative products is difficult because specifications are only partially known. There is a gap between the anticipated product specifications and the real product specifications during use. This will result in unanticipated complaints about performance, quality and/or reliability [Bro05].

2.5 Field feedback

2.5.1 Role of service centres
In a situation where product functionality, quality, costs and time-to-market are under strong pressure, it is necessary for a business process to have fast and adequate feedback from the market. The availability of feedback control loops is important for the improvement of business processes. For quality improvement, service centres are an essential element. In the service centre (call centre) the customer and the manufacturer have their first contact when

quality problems occur. These problems are a misfit between the customer's experience and the customer's expectations. These misfits find its origin in the Product Development Process (PDP). To prevent this misfit between the customer's expectation and the product, it makes sense to "listen to the voice of the customer" [Pet00].

When a complaint is covered by warranty, the service centre will try to repair the product as soon as possible at minimum costs. If a service centre is not assessed on its contribution to quality improvement, it has no motivation to spend time on finding the root cause of the problems and to communicate this to the other parties in the PDP. The service department is crucial in the PDP, because the service department is able to collect field failure data and data about customer use, and to analyse the relation between them [Pet00].

2.5.2 After-sales process

A way to achieve field feedback this is via the service process or after sales process (ASP). But with the current decreasing development time, the service process is not able to generate the required information in time.

The way in which service or after sales processes are organised in companies for consumer electronics is rather uniform (figure 2-6).
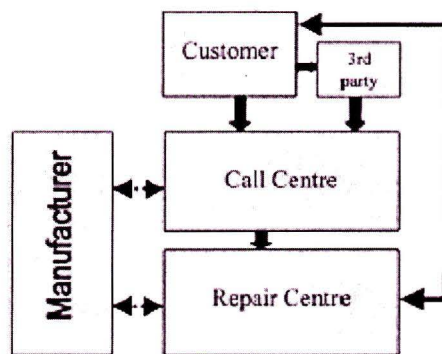
Figure 2-6: Organization structure of the ASP [Mol02]

The main question for analysing this structure is to learn how fast and with what level of detail product quality and reliability information reaches back from the customer to the manufacturer.

- **Customer**: The customer starts the ASP in the case that the performance of the product does not meet its expectations. The input of the customer consists of the failed product itself and the possibly some background information about the failure mode of the product.
- **Third Party**: In some cases a third party, either retailer or first line support group, does the intake of the product. Sometimes the product is pre-tested before it is sent to the repair centre. The failure data is sent to the call centre.
- **Call centre**: The main task of the call centre is to filter soft failures from the stream of calls and try to solve most of these problems immediately. The customers that have a product with a hard failure are dispatched to the repair centre. The role of the call centre is important, because it is the first contact in the ASP with the customer. They gather failure information from the customer, particularly where it concerns customer expectations and behaviour.
- **Repair centre**: The task of the repair centre is to repair the failed products that have hard failures. They receive failure information from the call centre and product and repair information from the manufacturer. The output consists of repaired products and failure information to the manufacturer.

- **Manufacturer**: The tasks of the manufacturer consist of providing the involved parties with the needed technical product information and hardware, payment for services performed to the other parties, deployment of information within the own organisation and trouble shooting when unexpected failures occur.

This structure describes the field feedback in an ideal way. In reality this is not always the case.

Petkova states a number of problems that reduce the quality level of the field feedback information [Pet03]:

- Failure information comes in too late in the product development process to make changes in the product.
- The available information is not complete enough for quality improvement.
- Feedback information goes not always to the right place in the product development process.
- Information is often hidden in a huge amount of data that is difficult to analyse.

As the feedback information is needed early in the product development process it is necessary to obtain this feedback information in another way. One way of obtaining this failure information early in the PDP can be executing a High Contrast Consumer Test.

2.6 High Contrast Consumer Test

Presently rejection of innovative products by customers within their warranty period is a major problem for many companies. To determine the root causes of these rejections two key sources can be ascertained:

- *Service centre data*. From consumer services centres a lot of consumer/product rejection information can be collected and analysed. As already mentioned in the previous paragraph the use of this field data has some disadvantages. The field feedback data is mostly too late available to use it for improvements at the product itself or in successor products, the data is not complete enough to use, the feedback goes not to the right place in the PDP or the failure information is hidden in a huge amount of data.
- *Consumer tests*. Customers are used in pro-actively determine potential product rejection issues during the design and development process so that changes still can be made to the product.

The advantage of a consumer test is that possible issues can be detected already during the product development process and subsequently changes can be made to the product. However, most consumer tests are often being conducted under ideal conditions with ideal products in a controlled environment with well defined "target customers" and pre-determined test procedures. In an attempt to make consumer testing more effective, an idea was developed for a new test procedure: the High Contrast Consuming Test (HCCT) [Boe03]. In this test the purpose is to observe critical and extreme customers using extreme products in realistic operating conditions. The assumption is that 'normal' products are not likely to fail at 'normal' customers. Therefore the method is developed to maximize the interaction between the customer and the product in order to provoke more failures. In a relative short period a number of contrast factors of extreme users and extreme products are selected. Extreme customers are customers that are heavy users of the product, or very critical on the functioning of the product. Extreme products can be defines as products that are narrowly functioning within the product specifications.

The purpose of this HCCT test is to accelerate failures and expose product usage issues as soon as possible. The HCCT method involves [Boe03]:
- Testing of product prototypes with a small number of critical and highly contrasting customers.

- Testing under near-realistic conditions.
- 'Think-Aloud'-protocol.

Near realistic conditions means that the conditions and environment in which the HCCT test is carried out should resemble the conditions and environment as where the user will use the product after purchase.

The 'Think-Aloud'-protocol is a technique applied in user testing, where participants are asked to vocalise their thoughts, feelings, questions and opinions, while interacting with a product as they perform a task.

The use of a High Contrast Consumer Test provides fast and focused feedback information on areas of customer uncertainties. Fast, because the test can be executed early in the development process. Focused, because the test is executed with carefully selected customers that provide the right contrast for the uncertainties that need to be investigated.

The set up of HCCT involves the following steps [Boe03]:
1. Identifying all new innovative product features to be tested.
2. Identifying extreme customers of the product and its new features via brainstorming.
3. Initiating a test session, which allows observation of these extremes customers using the test product under near-realistic operating conditions. The focus is on the unpacking, the installation process and the first use.
4. Prompting for the consumers' thought process via a unique "Think-aloud-Protocol".
5. Giving feedback information to the product development team; a consolidation of observations, thought processes and customer interviews for follow-up actions.

The HCCT method is designed not to test for compliance with specifications, but to maximize the variability in the interaction between product and customer. This done to provoke failures, early in the product development process, that would normally occur in the field of quality or (early) reliability problems. HCCT is introduced as a method of testing in the product development process to provoke failures that may lead to phase 1 and phase 2 failures of the roller coaster curve in the field. This is necessary because waiting for field failure information from the end consumer feedback is considered too slow, especially in high volume consumer products with short time-to-market and production cycle time. This is visualized in figure 2-7.

In the High Contrast Consumer Test the focus is on preventing failures in phase 1 (hidden 0-hour failures) and phase 2 (early wear-out) of the roller coaster curve. The goal is to get, in a short amount of time, a large number of realistic combinations of (extreme) customers and/or (extreme) products and analysing the resulting interactions.

The important success factors of the HCCT are Timing (position in the product development process), Speed (time required to obtain information) and the Quality (level of detail) of the information gathered. For a successful High Contrast Consumer Test, the following points will have to be clearly defined [Bas03]:

- Goal of the test (relevant phases of the product lifecycle, relevant classes of failures)
- Method (test structure (lab-conditions/at home), duration, relevant data, data gathering process, etc.)
- Selection of the participants in accordance with the predefined profiles (paragraph 2.7)
- Execution of the test
- Analysis of the obtained data and relating it to (potential) reliability issues.

13
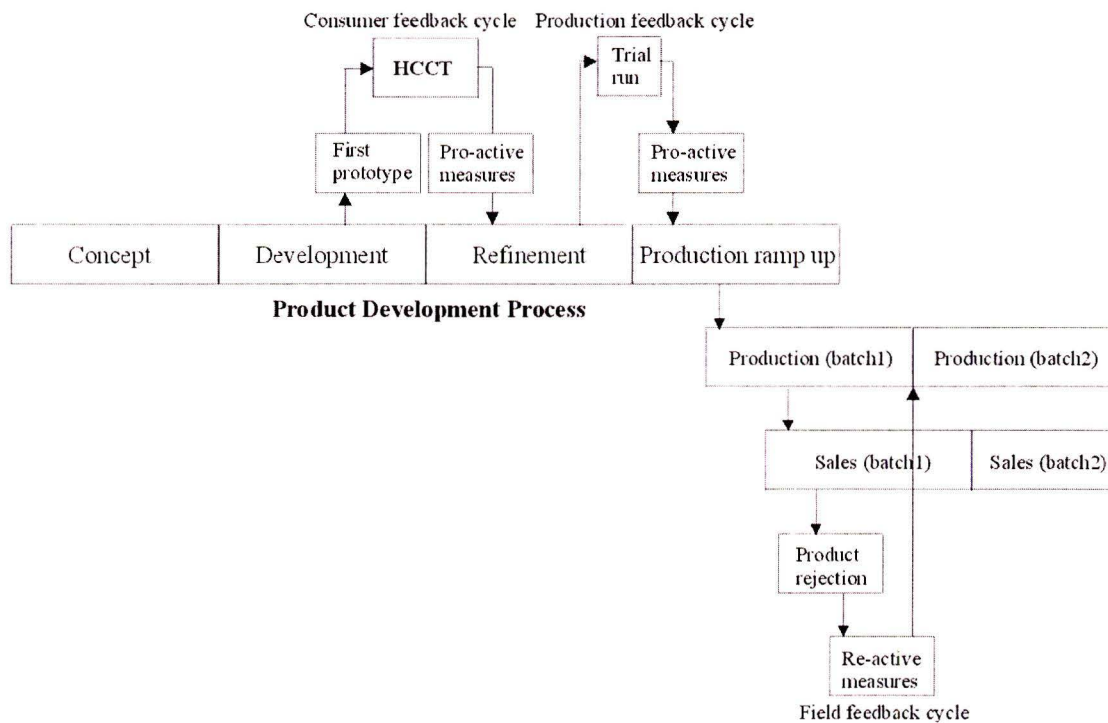
Figure 2-7: High Contrast Consumer Test in the PDP [Boe03]

Although the HCCT method will give a higher quality of feedback information, because the extreme users should represent all future customers of the product and use the product in an extreme way, there are some drawbacks. It is a difficulty how to select relevant contrast factors of these extreme customers and extreme products for the test. It is not clear which contrast factors should be used in which situations [Uit04]. A relevant contrast factor can be described as a contrast factor, which contributes significant to the differentiating of users and is measurable and thus therefore useful. Differentiation of users can be on characteristics like age, gender, religion, income or geographically, but it is desirable to divide users in subgroups that experience the product the same way. Therefore the market must be divided in categories, which have the same characteristics concerning the reaction to new innovative products. A way to do this is according the division of Rogers [Rog03]

2.7 User-groups

According to Rogers the adoption of an innovation is not the same for everyone. Adoption is the process where consumers decide to accept or reject a new product [Rog03]. Consumers adopt a new innovation differently, which means that the time it takes before a customer buys a new innovation is not the same. In figure 2-8 the customers are differentiated on the time that is taken to adopt new innovations. There are 5 categories of adoption that can be distinguished [Rog03]:

- *Innovators*: the first 3-5% of the individuals in a system to adopt an innovation. They have a major interest for technology and want to buy new innovations as soon as they are on the market.
- *Early adopters*: the next 10-15% of the individuals in the system to adopt the innovation. Like innovators they buy innovations very early in their life cycle, but unlike innovators they are not technologists.
- *Early majority*: the next 34% of the individuals to adopt the innovation. They are comfortable with technology, but they first want to see well-established references before

investing substantially. Because it's a large group of people, winning their business is a key for substantial profit and growth.

- *Late majority*: the next 34% of the individuals to adopt the innovation. Not as comfortable with technology as the early majority. They wait until something has become an established standard.
- *Laggards*: the last 5-16% of the individuals to adopt the innovation. These people want to stay as far as possible from new technology. They only buy the technological product when it's buried inside another product.
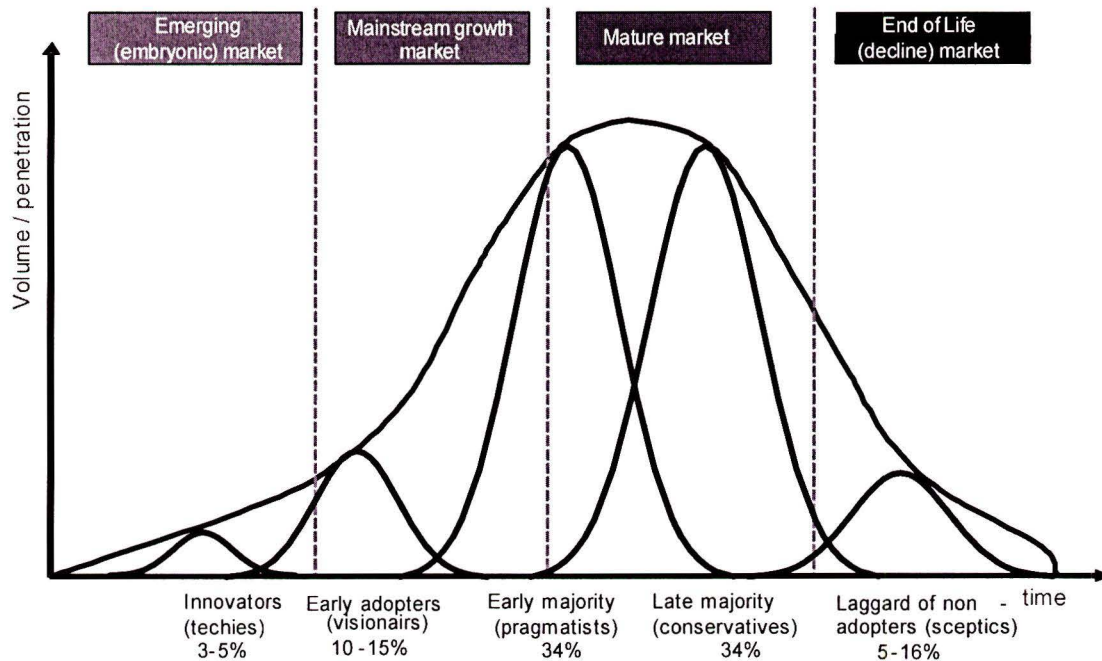
Figure 2-7: Customer categories on TALC [Rog03]

From a customer's perspective, making the decision to adopt a new technology is a high-risk one. Understanding the factors that affect customers purchase decisions is vital. Rogers identified five characteristics that influence the adoption process:

- *Relative advantage*: The degree to which an innovation is perceived as better than the idea it supersedes. The degree of relative advantage may be measured in economic terms, but social-prestige factors, convenience and satisfaction are also important components. The greater the perceived relative advantage of an innovation, the more rapid its rate of adoption is going to be.
- *Compatibility*: The degree to which an innovation is perceived as being consistent with the existing values, past experiences and needs of potential adopters. An idea that is not compatible with the prevalent values and norms of a social system will not be adopted as an innovation that is compatible.
- *Complexity*: The degree to which an innovation is perceived as difficult to understand and use. New ideas that are simpler to understand will be adopted more rapidly than innovations that require the adopter to develop new skills and understandings.
- *Trial-ability*: The degree to which an innovation may be experimented with on a limited basis. New ideas that can be tried on the instalment plan will generally be adopted more quickly than innovations that are not divisible. An innovation that is trial-able represents less uncertainty to the individual that is considering it for adoption, as it is possible to learn by doing.
- *Observability*: The degree to which the results of an innovation are visible to others. The easier it is for individuals to see the results of an innovation, the more likely they are to adopt.

15

Products that are perceived by customers as having greater relative advantage, compatibility, trial-ability and observe-ability, and less complexity will be adopted more rapidly than other products. Reversibly can also be said that products with more complexity and lesser of the other four characteristics will be rejected more probably than other products [Rog03].

Chapter 3: Research Model

In this chapter the scope and content of this research will be defined. First the research design is presented. In next two paragraphs successively the conceptual design of the research and the technical design of the research are described.

3.1 Research design

The design of this research is according to the methodology of Verschuren and Doorewaard [Ver95], which is visualised in figure 3-1. The research design is divided into the *conceptual design* and the *research technical design*.

In the conceptual design, the objective of the research will be presented together with an understanding of the design of the research. In this phase will be determined what and how much will be examined during this research. Consecutively the research objective, research questions, research framework and research definitions are described.

The research technical design deals with how the conceptual design can be realized by carrying out the real research. In this part decisions are made about the research material that is necessary to give an answer to the research questions. Also decisions are made how to approach the research subject, thus what research strategy should be followed, and a research planning should be made.
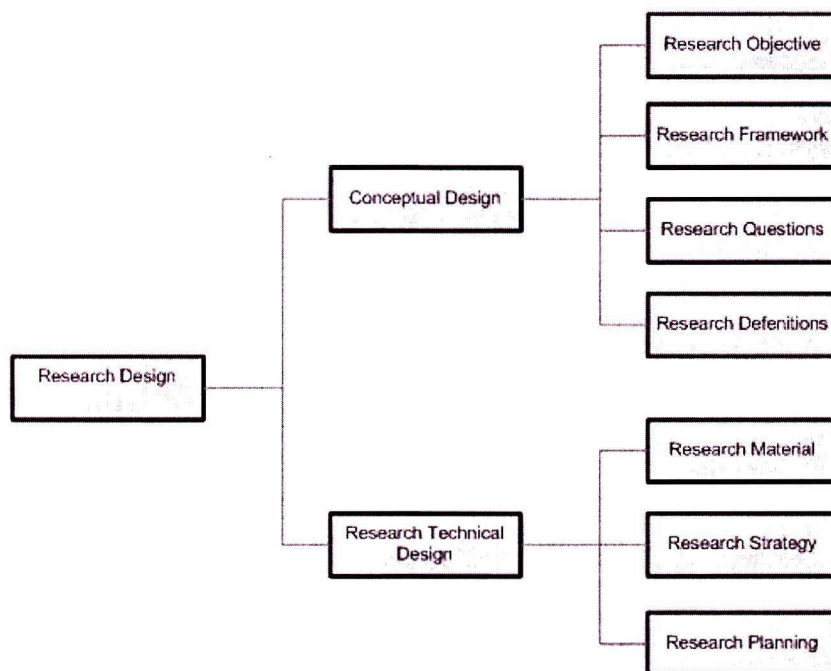

Figure 3-1: Research design [Ver95]

3.2 Conceptual design

In this paragraph the conceptual design of the research is outlined. It describes what is desirable to be achieved when performing this research and provides the definition of the design particularly. The conceptual design of this research consists of four different steps: *research objective, research questions, research framework* and *research definitions*.

3.2.1 Research objective

In the first place the objective of the research will be formulated. According to the definition of a research project in Verschuren en Doorewaard [Ver95] this research can be seen as a theory-oriented project. The main purpose of this research is not only to analyze the existing theory, but also to give suggestions for improvement of the HCCT theory.

Due to the increasing complexity of the products, the number of faults is also increasing rapidly. On the high-end television market the products are far more complex than several years ago. Nowadays, digital televisions contain a lot more software. This increase in complex software can lead to more problems in the functioning of the product. Due to the pressure on time-to-market, there is less time available for testing, so it is not possible to remove all faults in the products. This implies that there are still faults in the product when it enters the market. There is a chance that these faults will lead to failures when the product is in use and people will complain. As field feedback information is not available in time, failures have to be found during testing procedures before production starts. To create better insight in the customer-usage and to find existing faults or failures in the product, a consumer test can be carried out. As already described in chapter 2 the HCCT test is a method that is developed to accelerate failures and expose product use issues early in the PDP. However, the method is not designed to test a product for compliance with specifications. The focus is on provoking failures that lead to phase 1 and phase 2 failures of the rollercoaster curve. In the situation of LCD television the increase of software in the products will possibly lead to more software failures. These failures are internal product failures (hard failures) and can be classified as random failures (phase 3 of the rollercoaster curve).

Therefore *the goal of this research project* is to give suggestions for improving the applicability of HCCT theory for the detection of hard failures.

To reach this goal the project is divided in two phases. In the first phase will be examined if hard failures are still a relevant problem within innovative high-end consumer products. Therefore a experimental test is executed with an innovative high-end consumer product: a LCD-television. In the second phase of this research the existing literature about most commonly used test methods are reviewed and suggestions are given how the HCCT theory can be extended with aspects of other methods to improve HCCT for the detection of hard failures.

3.2.2 Research questions

The research objective that is stated in the previous paragraph can be reached by answering some research questions. These questions are formulated in such a way that they cover the goal of the project.

One of the objectives within the Trader-project is to find failures that become visible to the customer. There are still some faults present within the product, but it is the purpose to prevent these faults from becoming visible to the customer and leading to a product that won't meet specifications. To find out which failures are still in the product and how often they appear, a High Contrast Consumer Test can be executed. But to find out if it will be necessary for starting up a HCCT test, first has to be clear that there really are failures to be found in the product. If no failures can be found during a first experimental test, it is not very likely that during a consumer test failures will be found.

18

The research can be divided in two phases. In the first phase an experimental test is performed with a high-end LCD television to see if there are hard failures in a product that is already released to the market. In the second phase the different methods for testing are reviewed and compared with HCCT. These results can be used to improve HCCT for finding hard failures.

Phase 1: Experimental test

Preparing and executing a consumer test is only useful if it is likely that failures are found during the test. To see if there are still (hard) failures in the LCD-television first an experimental test is performed.

Therefore a first research question is stated:

*Are there still **hard** failures to be found in a high-end LCD-television after market introduction?*

In order to get a positive or negative answer to this question, first one person will test and use the product. This is done to discover if hard failures within the product can still be found during a limited test period of several days. If no failures show up during that period, it is unlikely that they will show up failures during a real consumer test, which should be carried out within a more limited time-period of a few hours.

If this research question leads to a positive answer that there still are failures in the product after market introduction, than it is useful to perform a consumer test. So if the answer is positive the second phase of the research will be started.

Phase 2: Improvement of the consumer test

In case the first research question is answered positive, it might be useful to carry out a consumer test like HCCT. As stated before the HCCT method is mainly used to find soft failures, while in the Trader project the focus lies more on finding hard failures in the products.

Therefore in this phase the following research question can be formulated:

How to improve the applicability of the High Contrast Consumer Test for the detection of hard failures?

To answer this research question it is necessary to formulate some additional sub-questions that first should be answered before an appropriate answer can be given to the research question that is stated above.

Possible relevant sub-questions may be:

How to find hard failures?

To answer this sub-question a description is given of commonly used test methods. For each method a number of characteristics are reviewed. One of these characteristics is the type of failures (hard and/or soft failures) that can be detected with each test method.

The theoretical model of HCCT testing is mainly used to find soft failures in products. The continuation of this research will be focused on how to use this HCCT theory in such a way that this method can be used more effectively in the detection and analysis of hard failures in

innovative products. Therefore it is important to analyze the strong points of HCCT testing and the limitations of the recent HCCT method in dealing with hard failures. This leads to the second sub-question:

What are the strong and/or weak points of HCCT testing?

If it is clear what the weak point of the HCCT method are for the detection of hard failures, it can be investigated how these weak points can be improved. In the development process already other methods are used for the detection of failures. A number of the most commonly used methods nowadays are reviewed to see if these methods can provide some improvements for the HCCT method. This leads to a third sub-question:

What test methods can be applied to improve HCCT's capacity of finding hard failures?

A certain number of characteristics are investigated for each method and an on the basis of these characteristics an overview of the different test methods is created. According this overview will be analysed if any the methods can contribute in some way to the HCCT method to find hard failures. From the answer to this third sub-question subsequently follow some improvements for HCCT testing.

3.2.3 Research framework

In figure 3-3 an overview is given of the way the project is carried out. As mentioned in paragraph 3.2.2 the research is carried out in two phases. This research framework shows the different steps that are taken in the two phases of this research.
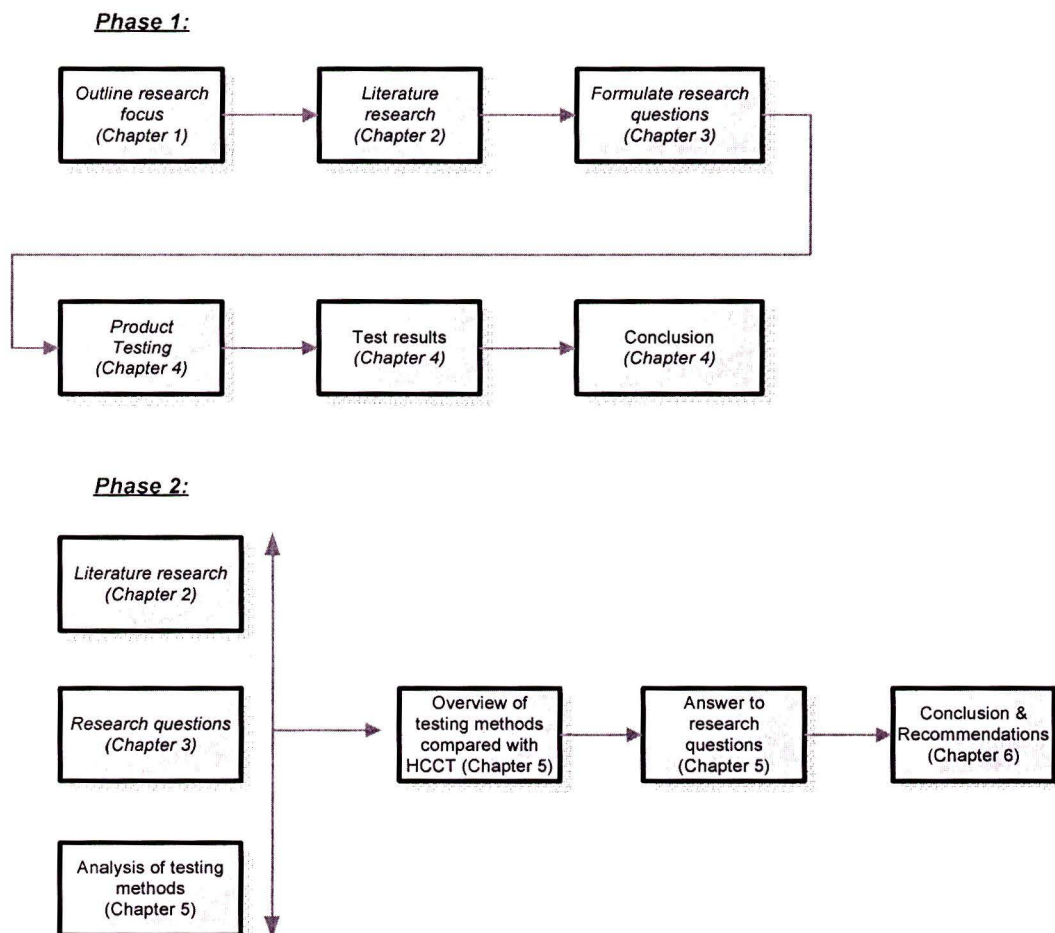

Figure 3-2: Research framework

3.2.4 Research definitions

For this research it is necessary to have a clear understanding of different types of failures that can occur. As already stated in chapter 1 there is a difference between *hard* failures and *soft failures*. The focus of this research is on hard failures. The definitions [Bro05] will be presented here again:

- *Hard failures:* Specification violations; Situations where the product is not able to meet both the explicit (technical) product specifications and customer requirements. Software failures causing out of specifications are also considered as hard failures.
- *Soft failures*: Customer expectation deviancies; Situations where in spite of meeting with the explicit product specifications a customer explicitly complains about the (lack of) functionality of the product.

3.3 Research technical design

The research technical design is a description in what way the conceptual design of paragraph 3.2 will be realized. The research technical design consists of three parts, namely *research material, research strategy* and *research planning*.

3.3.1 Research material

To provide an answer to the research questions it is important to determine which research material is necessary. The theory that is used in this report is derived from the available literature in the field of a number of disciplines:

- Quality and reliability
- Product development
- Testing
- Research methodology
- Failure data that has been collected from the performed test

3.3.2 Research strategy

In the literature different research strategies can be found. Verschuren and Doorewaard [Ver95] describe five different types of strategies. These strategies are: *survey, experiment, case study, grounded theory* and *desk research*. The research in this thesis is mainly based on literature research. Therefore this research can be characterised as an ground theory approach.

3.3.3 Research planning

In chapter 1 the problems companies of high-end consumer electronics have to deal with nowadays have been described. In this chapter also the focus of the research is outlined. A broad description of the literature has been given in chapter 2. The research methodology is presented in chapter 3. The test that has been preformed and the derived test data are described in chapter 4. In chapter 5 an analysis is given of the literature about different commonly used testing methods in product development and an answer is given to the research questions. Finally in chapter 6 the conclusions of the research are drawn and some recommendations for future research are presented.

Chapter 4: Testing

In this chapter, first an explanation is given about high-end LCD televisions and the product that is chosen for executing an experimental test. In the second paragraph an overview is given of the test goal, the test environment and equipment, and a description of the test procedure. In the last paragraph the results of the test are presented.

4.1 Product

In this paragraph first a description is given about the high-end LCD television in general. Then the product that is used for the experimental test will be described.

4.1.1 High-end LCD-televisions

The Trader project focuses mainly on the high-end television domain. In order to perform a consumer test a representative high-end product for this domain has to be selected. First should be defined what a high-end television is. A high-end television should have some new innovative functions, compared to mainstream CRT (Cathode Ray Tube) televisions. It should have a flat-screen, which is the case for Plasma televisions and LCD televisions. It also should be new on the market. There should also be the possibility to connect different kinds of peripheral equipment to the television. The LCD televisions are relative new on the market (a few years) and the development of LCD televisions is still in progress. The position of the LCD television on the technology lifecycle curve can be seen in figure 4-1, compared with CRT televisions which are on the market for a long time already [Uit04].
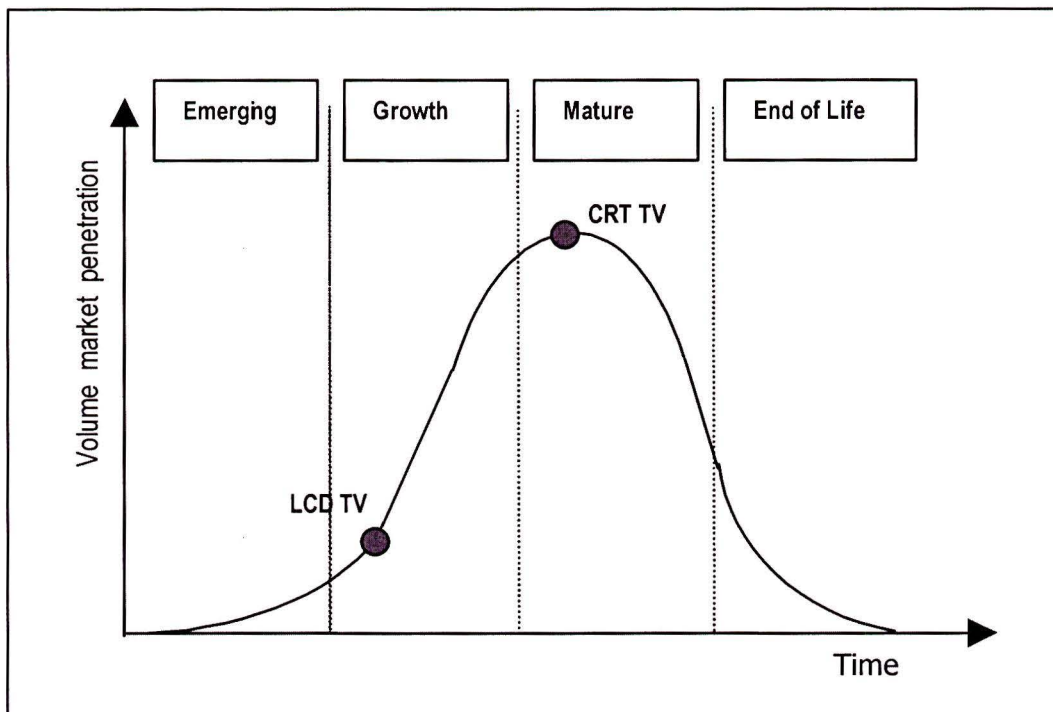

Figure 4-1: Position of television on technology lifecycle curve [Uit04]

4.1.2 Test product

In this project is decided to perform the test with a new type LCD-television. The product that is finally used for testing is a Philips 32PF9956 LCD-television (figure 4-2), which is on the market since the end of 2004.
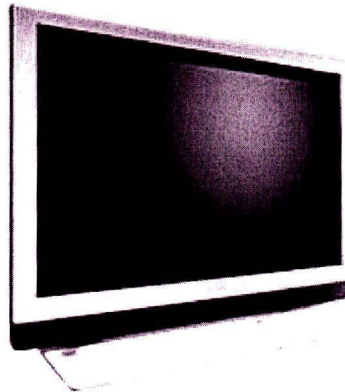
Figure 4-2: Philips 32PF9956 LCD-television

This LCD-television has a 32" inch flat screen (80 cm diameter) and is provided with some new and innovative features, like Pixel Plus-technology, USB-connection, HDMI-connection and memory-card-reader. The commercial price of the product is about 3000 Euro at the moment. A detailed overview of all features and specifications can be found in Appendix 1.

4.2 Testing

In this paragraph the execution of the experimental test is described. Successively the *test purpose, test environment and equipment* and the *test procedure* are presented.

4.2.1 Test purpose

The goal of Trader is to prevent failures from becoming visible to the customer. So it is important to test if hard failures can be found in the product that is already released on the market. To answer the research question stated in paragraph 3.2.2, if there are (hard) failures in the product, it is necessary to perform an experimental test with the television. This means that the television will be installed, configured and used to see if failures occur. One person will execute the test. If there are failures present within the television it is useful to carry out a consumer test with more test persons.

4.2.2 Test environment and equipment

For the experimental test with the television a special test room has been prepared. To test the television in realistic way, the test room has been furnished like a living room. Aside of the LCD-television some other equipment is necessary for the test. A coax cable connection was available to receive the usual television channels in the region. Peripheral equipment has been arranged to enable the testing as many as possible features of the television. The following peripheral equipment is used during the test: a DVD-player (Audiosonic), video-recorder (Samsung), USB-stick (Mycom), digital camera (Olympus) and a multi-media center (HP).

4.2.3 Test procedure

After the installation of the television in the test room, it is configured (according to the manual). This configuration includes the setup of general settings like time and language, channel installation, and a check if this is working properly. Next, one by one all functionalities of the television are used. For each function a stepwise approach according to the descriptions in the manual is followed. During these steps is observed if the function of

the television is working according to the specifications. Problems that occur are reported. To use some features it is necessary to have some additional products connected to it. For example, if one wants to use the USB port and its menu, an USB device, like and USB-stick has to be connected to the television.

The television and its functions, sometimes with peripheral equipment, have been used during one week for about 4 hours each day. So the total test period contains 20 hours. In this period several failures have been found. Every time a failure has been observed, it is tried to reproduce the failure. This means that the same steps or actions are performed as when the failure occurred, to see if the failure would occur again. To see what steps or actions where taken an infrared remote control logger was used. This is a device that records all the signals that are sent from the remote control to the television. These recorded signals are stored in a log file on a computer. If a failure can be reproduced, it means that there is really a problem in the product. To reproduce the failures it is necessary that the television can be put back in state before the failure occurred. To do this the television can be put back in so-called 'virgin mode'. This means that by entering a special code the television is restored to the original state, as when the product is bought.

The failures that have been found during the test are described in the next paragraph.

4.3 Test results

The problems that occurred during the first experimental testing of the television are summarized below. These problems can be divided in two categories, hard failures and soft failures. Both are mentioned, but for this research only the hard failures are of actual importance. However, the distinction between hard and soft failures is not always clear. The decision whether a failure is hard or soft is determined by the definition of Brombacher [Bro05]. Hard failures are the situations where the product violates the specifications. Soft failures are situations where, in spite of meeting explicit product specifications, there are complains about the functionality of the product.

Hard failures:

Installation
- Automatic channel installation: wrong name or no name given to channels.
- Manual channel installation: wrong name given to channels (NOS-TT in stead of NED2).
- Demo-installation: "Automatic installation" hangs. After starting the demo, channel search begins, after +/- 20 seconds it stops; showing an automatic channel installation screen. It is impossible to continue the demo or to get back to the demo-menu.

Teletext
- Hypertext function (Word Search): If a word searched for refers to a hidden text page, teletext stops searching and the user should exit teletext to be able to continue.

USB port
- Digital camera: pictures from the digital camera can be displayed but not rotated.
- Digital camera: when a digital camera (with empty battery) is connected to the TV but not used, after +/- 2 minutes the media browser menu is displayed.
- USB-stick: so-called hidden files on the USB-stick are displayed in the browse-menu.
- USB-stick: If there is update-software on the USB-stick the update-menu is started automatically. It is not possible then to read other data on the USB-stick.
- Slideshow: When using the slideshow function with so-called "transition-effects" for displaying pictures from a camera, it is impossible to pause the slideshow during a transition (pause signal is ignored). When switching of the transition-effects function, the

slideshow can be paused during a transition   between to successive pictures (pause signal is remembered and executed at the next picture)

Others
• <u>Smart Surf</u>: during installation of smart surf channels, TV sound falls out
• <u>On Timer</u>: TV turns on at the right channel but jumps to the first channel after 1 or 2 seconds (non-reproducible!).
• <u>Channel lock</u>: locking a channel changing the code unlocking the channel. The child lock still displays the channel as being locked.

Soft failures:

Installation
• <u>Manual channel installation</u>: channel search is only possible in forward direction (right cursor). Left cursor goes back to the installation menu.
• <u>Manual installation</u>: channel fine-tuning is not done automatically; detection of the next channel's signal is done automatically.

Screen
• <u>Picture quality</u>: visible pixels (even at great distance), stains and stripes/lines.

Sound
• <u>DVD</u>: DVD sound volume is much softer than for TV programs or VCR sound.
• <u>Sound intensity</u>: sound intensity is not displayed. Even during volume control actions you don't know at what level the volume is at that moment.

Others
• <u>Channel lock</u>: It is impossible to change the channel number of locked channels.
• <u>Safety:</u> Electricity cable of TV gets stuck between TV and table support. This could result in a serious safety issue.

4.4 Conclusion

The purpose of the experimental test with the LCD-television that is described in this chapter was to give an answer to the first research question that is stated in paragraph 3.2.2: *Are there still hard failures to be found in a high-end LCD-television after market introduction?*
As a result of the experimental test that has been executed, a considerable number of failures have been found, as can be seen in table 4-1.

Tabel 4-1: Test results

	Hard failures	**Soft failures**
Installation	3	2
Screen	-	1
Sound	-	2
Teletext	1	-
USB port	5	-
Other	3	2
Total	**12**	**7**

After a test time of 20 hours can be seen that there are still hard failures in the product after market introduction. Therefore the conclusion can be drawn that further research is justified. In the next phase of this research will be tried to give an answer to the other research questions that are stated in paragraph 3.2.2.

Chapter 5: Analysis of testing methods

In this chapter an analysis is made of different testing methods and an answer is provided to the research questions. In the first paragraph the approach of the analysis is outlined. In the second paragraph a description is given of different types of testing methods. A number of characteristics are for tests methods are described in the third paragraph. Next, an overview is made of these characteristics for each method. Finally, in the last paragraph the applicability of the test methods for improving HCCT is explained, and all the research questions are answered.

5.1 Analysis approach

In the previous chapter is proved that there are hard failures in a high-end consumer electronics product after market introduction, and that it can be useful to carry out a consumer test. This chapter will deal with *Phase 2* (figure 5.1) of this research and will provide answers to the research questions that are stated in paragraph 3.2.2.

Phase 2:
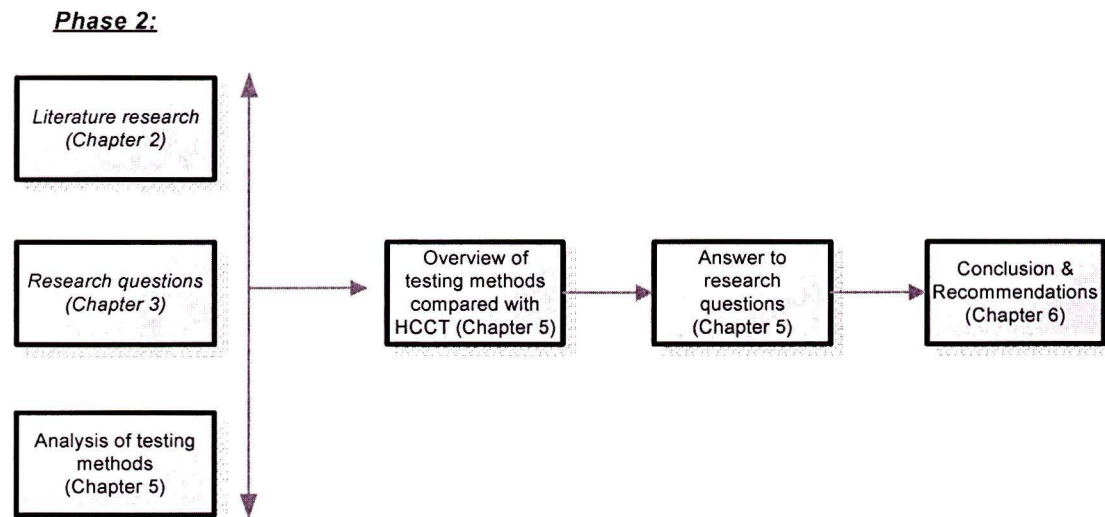
Figure 5.1: Analysis approach

Within the Trader project the focus is primary on finding hard failures. Thus when performing a consumer test it is important to do this in a way that as much hard failures as possible can be found. The goal of this second phase of the research will be providing improvements to the HCCT testing approach to allow the detection of hard failures. With the use of existing theory and the results of the experimental test the purpose is to give an answer to the research questions stated in chapter 3. The main research question was formulated as follows:

How to improve the applicability of the High Contrast Consumer Test (HCCT) for the detection of hard failures?

Before this question can be answered, an answer should be provided to the relevant sub-questions that are also stated in paragraph 3.2.2.
The first sub-question is:

How to find hard failures?

26

To provide an answer to this research question a description is given of different types of (proactive) testing methods that are commonly used nowadays (paragraph 5.2). Through a number of characteristics for each method (paragraph 5.3) an overview of the methods is generated (paragraph 5.4). From this overview of the methods can be distracted which methods can contribute to find hard failures.

In paragraph 5.5 the other sub-questions are answered. The second sub-question is:

What are the strong and weak points of the HCCT method?

When the strong and weak points of the HCCT method are investigated, it should be clear which points of the method need improvement. For the improvement of the HCCT method the analysis of the other test methods will be used, which leads to the third sub-question:

What test methods can be applied to improve HCCT's capacity of finding hard failures?

If these three sub-questions are answered, conclusions can be drawn in order to answer the main research question.

5.2 Test methods

The process of creating a new innovative consumer product requires a lot of testing. As a result of the increasing complexity of innovative products and increasing customer demands, it is harder for companies to create products that are functioning according customer expectations without failures. However it is important for a company to deliver a good and reliable product. During the product development process the product therefore undergoes a lot of tests to ensure its quality and reliability. The definition of a test method has to be seen in a broad way. Not only the tests where a real product or prototype is used should be taken in account, but also other approaches that are used to provide possible failures in a product. The different types of testing methods can be divided in 3 categories: *hardware tests, software tests* and *consumer tests*. In the next three sub-paragraphs for each category some commonly used methods are briefly described.

5.2.1 Hardware testing
Some frequently used methods for hardware testing are Quality Function Deployment (QFD), Failure Mode and Effect Analysis (FMEA), Accelerated Stress Testing (AST) and Prototype testing. These methods are used in most product development processes for high-end consumer products. In this paragraph a short description of these four methods is given.

Quality Function Deployment (QFD)
Quality Function Deployment (QFD) is a structured approach for defining customer needs or requirements and translating them into specific plans to produce products to meet those needs. It has to be mentioned that the QFD method is not really a test method, but an approach for optimizing the product, according customer needs. There is no real product that is tested. Nevertheless the method is described, because QFD is executed already in the concept phase of the product and if it is done well the method can prevent possible failures.
The QFD method has three fundamental objectives: These are [Zai95]:
  - Identify the customer
  - Identify what the customer wants
  - How to fulfil the customer's wants
A QFD matrix, or the house of quality tables, is used to provide information on customer requirements, design requirements and the correlation between these requirements [Zai95]. The "voice of the customer" is the term to describe these stated and unstated customer needs or requirements. The voice of the customer is captured in a variety of ways: direct discussion

or interviews, surveys, focus groups, customer specifications, observation, warranty data, field reports. This understanding of the customer needs is then summarized in a product planning matrix or "house of quality". These matrices are used to translate higher level needs into lower level product requirements or technical characteristics to satisfy these needs [web1].

However, with innovative products it is difficult to determine customer requirements exactly. The method can be used for preventing hard and soft failures, but the method is time consuming.

Failure Mode and Effect Analysis (FMEA)
FMEA is a procedure and tool that helps to identify every possible failure mode of a process or product, to determine its effect on other sub-items and on the required function of the product or process. The FMEA is also used to rank and prioritize the possible causes of failures as well as to develop and implement preventative actions, with responsible persons assigned to carry out these actions. [web1]

Failure modes and effects analysis (FMEA) is a disciplined approach used to identify possible failures or problems of a product or service and then determine the frequency and impact of the failure already early in the development process.

Generally in a subjective analysis, accuracy will depend on the participant's knowledge of the product [Por04]. On general information, the results will highly repeatable from group to group. Detailed information on failure modes and corrective actions will be highly dependent on the design group doing the analysis. Conducted properly the FMEA can take 5-10% of the total labour for a development project, so it can be seen as a time-consuming test. For executing the FMEA there are between two and ten persons needed. These persons are experts with knowledge about the product. The test is mainly used to find hard failures only.

Accelerated stress testing (AST)
Accelerated stress testing is used to find reliability problems already during product development. In classical AST products are tested according a commonly accepted test standard/generic list against the constant failure rate model. A risk of testing against a constant failure rate is the poor correlation to the actual field performance [Luy00].

A number of tests are mentioned here, which all are based on stress testing, like accelerated life testing; stressor-susceptibility testing and highly accelerated life testing (HALT).

Accelerated life testing
Inadequate time to complete life testing is a problem in making reliability estimates. A number of acceleration methods may be used to counter the difficulties in performing life testing within time deadlines. These accelerated tests can roughly be divided into two categories [Lew96]:

- Compressed-time testing: In this type of test the product is used more steadily or frequently in the test than in normal use, to reach a design life target in a relatively short period of time. The loads and environmental stresses are maintained at the level expected in normal use. However, it is difficult to perform the test under field conditions that the product might face in actual use, but nevertheless some acceleration is possible.

- Advanced-stress testing: This test may be employed to accelerate failures as a result of increased loads or environmental factors that are applied to the product and result in increasing failure rates. Both random failures and aging effects may be the subject of advanced-stress testing. But also placing products under a high-stress level for a short period of time may be considered to reveal the early failures from defective manufacture [Lew96].

Stressor-susceptibility testing

The stressor-susceptibility concept is based on the analysis of physical failure mechanisms in products. A stressor is defined as a physical stress influencing the quality and reliability of products. While susceptibility of a product to a certain failure mechanism is defined as: a probability function indicating the probability that the product will fail after a certain time under a given set of stressors [Luy00].

The stressor-susceptibility concept is used to determine the relevant failure mechanisms from the field. By deriving this relevant field information, there are two common strategies that can be used to accelerate the stress:

- *Increase the probability of extreme stress*. One strategy is to increase the probability of the occurrence of the failure by increasing the operation cycles of the product under test conditions given that the failure mechanisms remain the same for both the test and the field (figure 5-2). The advantage of using this strategy is that the products are tested under real but extreme operating conditions and that it is easy to translate from testing conditions to actual field conditions [Luy00].
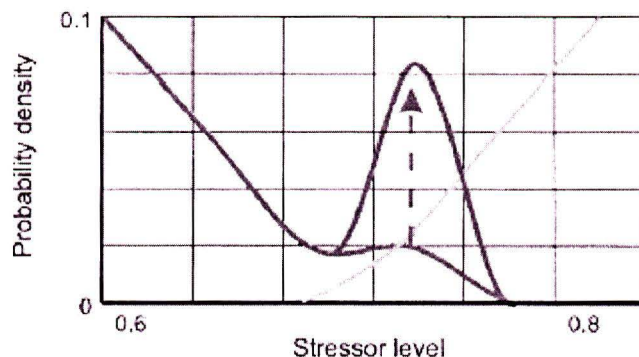
Figure 5-2: Increasing the probability of extreme stress

- *Increase the level of extreme stress.* The other strategy is to increase the severity of the real but extreme stress given the failure mechanisms remain the same at both field and test. This requires the knowledge of the stresses and their relevant ranges to elicit the same failure mechanisms. However a strong understanding of the stress severity is necessary to maintain the link between the test and reality (figure 5-3) [Luy00].
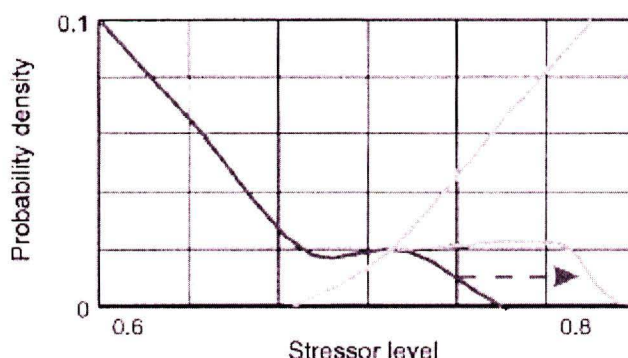
Figure 5-3: Increase the level of extreme stress

Highly Accelerated Life Testing (HALT)

The basic principle of highly accelerated life testing is the margin discovery process. The goal of this process is to determine the margins between the service conditions of the product and the functional limits and the destruct limits. HALT applies one stress source at a time to a product at elevated levels to determine the levels at which the product stops functioning but is not destroyed (operational limits), the levels at which the product is destroyed (destruct limit) and what failure modes cause the destruction of the product [Por04].

HALT has a significant advantage over traditional reliability tests in identifying failures modes in a very short period of time. HALT typically takes two or three days, while traditional tests will take from a few days to several months. Also HALT will identify several failure modes providing significant information for the design engineers to improve the product. However, a disadvantage of applying HALT is that the possible interactions among different stresses, which are valid in the field, may be ignored [Luy00].

Prototype testing

After designing a new product, a company usually manufactures a prototype of the product to test it. This prototype test enables the company to detect and correct potential product problems. According to Ozer [Oze99] there are three types of prototype testing. The first is *alpha testing*, in which experts test the prototype under laboratory conditions within the firm to see if it delivers its intended performance. The second type is *beta testing*, where real customers can use the product for a specified time period within their own usage environment and report their experiences. Finally, in *gamma testing* people use the prototype indefinitely and report any problem they might discover.

Ozer states that prototype testing is time consuming and needs a large sample of test prototypes. The number of stressors that are used in the test is large, because the customers use the prototype in their real environment.

5.2.2 Software testing

Due to increasing amount of software elements in high-end consumer electronics products, software reliability prediction is necessary. The problem with the increasing complexity of the software in products is that the possibility of failures is also increasing. Therefore software testing becomes more important in the development and testing of new products. As in the hardware tests, like accelerated stress tests, failures only occur in a certain predicted range of possibilities. A certain stress is increased until a failure occurs. In software testing this is more complex. The range of possible and unexpected digital states within software is much higher and more extreme situations are possible. The complexity of the features and the increasing number of (software) features that have to cooperate in a system can lead to unexpected problems. The integration of functional domains is making the user-product interaction more complex and the increasing interaction possibility among products is making the product-product interaction more complex. For example if several buttons are pushed at the same time the function does not work or something unexpected occurs. This makes it difficult to test all the possible functions in advance to make sure that the software in the product does not contain faults. Therefore it is important that the product is used in customer environment and (extreme) users test the product.

Software testing can be divided into different test phases: *unit test, function verification test, system verification test, performance verification test, integration test* and *beta test*. Each phase targets different types of software bugs and no single phase is adept at catching them all. Each test phase has its own associated limitations and costs, but to be consumer-ready the software must cross through all these phases [Lov05].

Unit testing

The unit test is the first real test phase that a piece of software undergoes and targets the extraction of obvious coding errors. Those errors may be basic, but if missed they could become very disruptive to later testing activities. Typically the programmer does the test on his individual code, as it requires detailed knowledge of the internal program design and code. The environment for the unit test is primarily a single computer system.

Limitation of the method is that a single major component of a complex software product usually consists of many individual modules or objects, which are all working together to deliver the component's functions. Different programmers develop these modules, which results in that testing is largely isolated to a single module at a time. This isolation enables the unit test to tight focus on the code of each module, but it prevents the tester from seeing how the code will behave in the realistic environment.

The ability for improvement here is large, because this is the first test of the software in an early stage of the development process [Lov05].

Function verification test (FVT)

After completion of the unit test, the individual modules are integrated into a package for a certain function. The function verification test team focuses on validating the features of an entire function of a component. Main question here is: is the function performing as it is designed to?

The FVT can be performed on native hardware platforms or simulated environments.

Limitations of the FVT is that the scope is only limited to a single function or component, rather than to the overall software package.

System Verification Test (SVT)

After completing the FVT the system verification test takes all the software components and tests them as a whole, focusing on the software's function. SVT views the software from the perspective of a customer seeing the whole product for the first time. The SVT effort pursues the most complex defects in the software and it also will help identify defects such as architectural disconnects.

SVT is where the software meets the real, native hardware for the first time.

The execution of the method is limited to a single product. If the product has to cooperate with other products, the focus of SVT is not broad enough to catch cross-product defects.

Performance Verification Test (PVT)

The performance verification test objective is to identify performance strengths and weaknesses. The team designs measurements that target performance-sensitive areas identified during the software design's stage or by customers executing within existing environments. PVT may also focus on how the software compares to industry benchmarks.

The PVT searches for bottlenecks that limit the software's response time and throughput, which usually are related to the interaction between the software and the hardware or excessive code path lengths or key functions. In PVT is the purpose to make the software stable, this in opposition of SVT where is tried with load/stress testing tools to prove that the software is not stable.

Integration test

Integration test targets problems related to how different software products interact. It integrates the new software into a simulated customer environment.

The test is often done in parallel with the Beta test, and sometimes continues after general availability of the product. The goal is to stay one step ahead of the customers in exercising extremely complex environments, improving usability and exploring other soft failures.

Limitation of the integration test is that because of its broad view, it is dependent on the previous test methods to successfully extracting bugs and significant stability problems. Also, while the integration test team attempts to achieve a customer-like environment, it can't

possibly be all-inclusive, but must try to be representative. The effectiveness will be limited by the quality and quantity of customer information. Therefore talking directly to customers for better understanding will be necessary.

Beta test

For this test the product or software is passed to real customers. These customers deploy the software in a real environment with all the associated variability and complexity.

An obvious limitation of the beta test is that it can't cover every possible environment. This is mostly due to time and cost limitations for the test.

Software Reliability Engineering (SRE)

The demand for complex hardware/software systems has increased more rapidly than the ability to design, implement, test and maintain them. When the requirements for and dependencies on software increase, the possibility of problems from software failures also increases. Software reliability is defined as the probability of failure-free software operation for a specified environment [Lyu96], [Mus80]. A 'failure is defined as: an unacceptable departure of program operation from program requirements. A 'fault' is the software defect that causes the failure. Failures usually occur only when a program is exposed to an environment for which it was not designed or tested. Therefore software reliability is essentially measuring if the design is able to function properly in its expected environment [Mus80].

Software Reliability Engineering is a method that is not only based on improving software reliability, and availability, but also the development of the software according customer needs. Therefore SRE is defined as the quantitative study of the operational behaviour of software-based systems with respect to user requirements concerning reliability [Lyu96].

SRE includes:

- Software reliability measurement, which includes estimation and prediction, with the help of software reliability models established in the literature
- The attributes and metrics of product design, development process, system architecture, software operational environment and their implication on reliability
- The application of this knowledge in specifying and guiding system software architecture, development testing, testing acquisition, use and maintenance.

5.2.3 Consumer testing

Consumer tests are used to observe how consumers react on new innovative products and how the product performs under real consumer stresses. Two methods are mentioned: *the High Contrast Consumer Test (HCCT) and Usability testing*. A description of HCCT is already given in paragraph 2.6, so in this paragraph only usability testing is described.

Usability testing

This method focuses at testing for 'user-friendliness'. Clearly this is subjective, and will depend on the targeted end-user or customer. User interviews, surveys, video recording of user sessions, and other techniques can be used. Programmers and testers are usually not appropriate as usability testers.

Usability testing measures the suitability of the product for its users, and is directed at measuring the effectiveness, efficiency and satisfaction with which specified users can achieve specified goals in particular environments or contexts of use.

Effectiveness is the capability of the product to enable users to achieve specified goals with accuracy and completeness in a specified context of use. Efficiency is the capability of the product to enable users to expend appropriate amounts of resources in relation to the effectiveness achieved in a specified context of use. Satisfaction is the capability of the software product to satisfy users in a specified context of use.

Testing should be done under conditions as close as possible to real conditions under which the system will be used. It may be necessary to build a specific test environment, but many of the usability tests may be part of other tests.

Research shows that if users are selected who are representative, 3-5 users are sufficient to identify most of the usability problems. 8 or more users of each type are required for reliable measures and with 15-20 users almost all reliability problems are discovered [Nie93]. In practice, the number required would depend on the variance in the data, which will determine whether the results are statistically significant.

An overview of different usability techniques can be found in Appendix 2.

5.3 Test characteristics

To make a classification of all the different testing methods a number of characteristics is reviewed for each method. These characteristics are selected in such a way that applicability of the method for the improvement of HCCT for the detection of hard failures can be evaluated.

The following characteristics will be evaluated for each research method.
- Type of failures to find with the method (hard/soft failures)
- Test coverage
- Position of the test in the PDP
- Ability for changes/Impact of changes
- Test type
- Duration of the test
- Test environment
- Type of test persons
- Number of products needed for the test
- Product/customer selection criteria

5.3.1 Failure types
As stated before in paragraph 1.2, two types of failures can be determined: *hard failures* and *soft failures*. Hard failures are specification violations; situations where the product is not able to meet both the technical product specifications and customer requirements. Soft failures are situations where the product meets the explicit product specifications, but where the customer complains on the (lack of) functionality of the product.

In this research the focus is on finding hard failures. Therefore it is important that the test method can be used to find these hard failures.

5.3.2 Test coverage
The test coverage is the amount of failures that are found during a certain test compared with the total failures that are still present in a product.

The test coverage is the ratio between tested specifications and total specifications. If a test method only covers a few specifications, than not all the severe problems might be found. When a small test coverage is used and only a few specifications are tested, than the stressors applied during the test is also few.

5.3.3 Position in the PDP
It is important to find failures in the product as early as possible in the development process to be able to make changes in the product when failures occur. When problems are discovered earlier, there is more time to fix these problems and they can be fixed at lower costs.

Ozer [Oze99] makes a distinction between different testing phases for new product development: Concept testing, Prototype testing, (Pre-) Market testing, Launch.

In this thesis the PDP will be divided in four phases: *concept phase, development phase, prototype phase* and *production phase*.

5.3.4 Ability for improvement/Impact of changes

Reliability studies during design and development are extremely valuable, when they are available at a time when design modifications or other corrections can be made at much less expense than later in the product life cycle [Lew96].

The ability for improvement is in certain way related to the two previous categories, test coverage and the position of the test in the PDP. If a test method has broad test coverage probably most of the problems will be found during the test and can be fixed. Thus there will be a high ability for changes. But if the test is executed in a later phase of the PDP, and failures are discovered later, it will be more difficult and more expensive to make changes, which means that making the changes have a large impact in the development process.

5.3.5 Test type

Depending on the phase in which a development process is at a given moment in time, three types of tests can be identified [Oud04].

The first type of test that can be applied is the *analysis test*. To test whether the right product requirements have been defined, failures are provoked that reflect situations that may happen later. For the specifications defined, it is checked whether they are realistic. The test product has only limited resemblance with the final product [Luy00].

Later in the process follows the *verification test*. Verification means checking whether the development is according the defined requirements. The goal is to find the remaining unanticipated failure mechanisms in a largely completed design in order to generate feedback for the development group and to verify chosen solutions.

In the final phase of the process follow *validation tests*. These tests are aimed at checking if the product does meet the intended requirements. The purpose of the validation is to exclude that uncertainties are remaining in the product or its use.

Verification and validation both require a product to perform the tests on.

5.3.6 Test duration

The time available before a decision must be made in order to proceed to the next level of the product development process is a constraint for testing. Due to the high pressure on time-to-market there is less time available for testing. Therefore it is important that executing a test can be done within a short period of time. For example in stress testing, acceleration tests can be performed. In this type of tests the stress cycle frequency or stress intensity is increased to obtain the failure data in a shorter period of time. For other test methods it is not possible to accelerate the test time, but should be decided what will be an appropriate test sample. A large test sample probably will discover a larger amount of failures, but will also take more time. If the test sample is too small it is possible that severe problem will not be found.

5.3.7 Test environment

There are different places where the test can be executed. In this thesis the distinction is made between *office, laboratory* and *home*. A test can be performed in the office when no products are needed or available for finding (possible) problems. Stress tests and software test are mostly executed in laboratory environments. The environment will be build to be as realistic as possible to the user environment in which customers will use the product. To have a real customer environment, tests can also be executed at a customer's home, where the product will be exposed to far more stressors that can be simulated in laboratory experiments.

5.3.8 Test persons

As the goal of this research is to develop a better consumer test for LCD televisions it is important that customers can be involved in carrying out the test. For each test method will be reviewed if users or experts should execute the test.

5.3.9 Number of test products

This category will indicate the number of test products (or parts of the product) needed to carry out a certain test.

Reliability testing is constrained by cost. The achievement of a statistical sample, which is large enough to obtain reasonable confidence intervals, may be too expensive. Accordingly as much information as possible must be obtained from small statistical samples. The use of failure mode analysis to isolate and eliminate the mechanism leading to the failure may result in design enhancement long before sufficient data is gathered to perform formal statistical studies.

5.3.10 Product/customer selection criteria

In this category is reviewed in what way the customers, that are involved in the test, are selected. This selection can be done according to a statistical normal distribution, in a random way or only using extreme values. For most of the test methods the test participants are selected in a random way. The drawback is this way of selection is that only the failures are found that occur under normal test conditions, and probably not all the failures will be discovered that only will occur in extreme situations. For the HCCT test only extreme customers are selected.

5.4 Overview of characteristics and methods

For all the test methods in paragraph 5.2 an analysis is made of the test characteristics that are described in paragraph 5.3. These results are presented in a general overview in table 5.1.

Table 5.1

	Failures types (hard/soft)	Test coverage	Position in PDP	Impact of changes	Test type	Test duration	Environ-ment	Test persons	Number of test-products	Product/ customer selection criteria
Hardware tests										
QFD	Hard/soft	Critical customer require-ments	Concept	Low impact Easy to make design changes	Analysis	Time consu-ming	Lab/office	User/ experts	None	---
FMEA	Hard	Top 20% of corrective action issues represent 80% of potential problems	Concept, Development, Prototype	Low impact/ Easy to make design changes	Analysis	5-10% of develop-ment process	Lab/office	Experts	None	---
AST	Hard	Only certain aspects (stressors) tested	Development, Prototype, Pre-production	High impact	Verification	Relative quickly (few weeks)	Lab	Experts	For each stressor some products needed	Random
Prototype	Hard/soft	Large number of stressors tested	Prototype	High impact/ Expensive to make changes	Validation	Time consu-ming	Lab/home	User/ Experts	Large sample	Random
Software tests										
Unit test	Hard	Coding errors	Development	Low impact	Analysis	Weeks	Lab	Experts	Large sample	Random
Function Verification Test	Hard	Only failures of the tested function	Development	Low impact	Verification	Weeks	Lab	Experts	Large sample	Random
System Verification Test	Hard	Coopera-tion of the functions	Development, Prototype	Low impact	Verification	Weeks	Lab	Experts	Large sample	Random
Performance Verification Test	Hard	Interaction of software and hardware	Development, Prototype	High impact	Verification	Time consu-ming	Lab	Experts	Small sample	Random
Integration Test	Hard/soft	Broad coverage	Prototype	High impact	Validation	Time consu-ming	Lab (Near realistic)	User/ Experts	Small sample	Random
Beta test	Hard/soft	Broad coverage	Prototype	High impact	Validation	Time consu-ming	Home	User	Small sample	Random
Consumer tests										
Usability Testing	Hard/soft	40-80% of the problems	Development, Prototype	High impact	Validation	Few weeks	Lab/home	User/ Experts	Small sample	Random
HCCT	Hard/soft		Development, Prototype	High impact	Validation	Few weeks	Lab/home	User	Small sample	Extreme

5.5 Applicability of the methods

In this paragraph the applicability of the test methods for the improvement of HCCT is investigated. Before an answer can be given, first an answer to the sub-research questions is provided.

5.5.1 Hard failures

The first research sub-question that should be answered was:

How to find hard failures?

The conclusion that can be drawn from the overview that is presented in paragraph 5.4 is that all the described methods are capable for finding hard failures.

5.5.2 Strong and weak points of HCCT

In this paragraph an answer will be provided to the second research sub-question. This question was formulated as follows:

What are the strong and weak points of HCCT testing?

An analysis is made of the HCCT method and its strong and weak points. The purpose of this thesis is to improve the HCCT method. Therefore based on the weak points is tried to give some improvements derived from the other test methods.

The HCCT method was developed because it was found that the traditional consumer tests were often conducted too rigidly to give useful results [Boe03].
HCCT focuses on the testing of a small number of critical and highly contrasting consumers with product prototypes in a short amount of time. The selection of these extreme customers is one of the strong points of the method, because for each tested function or product the consumers are selected that will use the product in an extreme way. The extreme consumers will probably find failures in the product earlier than consumers that will use the product in a normal way. Also is expected that with extreme customers more different types of failures are found, due to unexpected behaviour.
Another strong point is that only a small number of test persons and test products are needed for the test. In other tests the selection of test products and participants are selected in a random way. Due to this random selection the expected failures that will be found during the test will behave according a statistical normal distribution. This means that only the most common failures will show up during the test. The failures that can only be found under extreme situations will probably not be found. The purpose of HCCT is to select the products and participants for the test in such a way that the failures caused in 'extreme' situations also will be found.

From the view of finding hard failures, a disadvantage of the HCCT method is, that it is mainly used to find soft failures during the unpacking, installation, setup and first use of the product.
As stated above, a strong point of the HCCT method is the use of highly contrasting consumers and products. However, the drawback is that it is not always clear how these contrasting customers and products should be selected.
Furthermore, it is obvious that these contrast factors will not be the same for all products. In the case of the high-end television domain other contrast factors are relevant than for example in the mobile phones domain. Relevant contrast factors for the LCD-television domain can be:
- Installation of a high-end product. Does a customer have a lot of experience with the setup of televisions or is this product the first time the consumer uses this kind of product.

- The use of peripheral equipment. Does the customer only use the television or is he/she intending to use a lot of peripheral equipment.
- Intensity of use. Will the television be used very often or just occasionally?

5.5.3 Use of other methods

The disadvantages of the HCCT method are described in the previous paragraph. To improve the HCCT method on these points the third research sub question needs to be answered.

What test methods can be applied to improve the HCCT's capacity to find hard failures?

In the overview presented in paragraph 5.4 can be seen that all test methods can be used for finding hard failures. However, for the improvement of HCCT not all test methods are useful. In the first place, the purpose of the HCCT method is to execute the test with real customers. Therefore, the test methods that are qualified for a possible improvement for HCCT are these methods that are also using real customers for its test. As can be seen in the overview in paragraph 5.4 possible methods are: prototype testing (hardware test), beta testing (software test), system usability testing and usability testing (consumer tests). A drawback of these methods, especially the prototype test and the beta test, is that these test methods are time consuming. With the problem of high-pressure of time-to-market nowadays, it is necessary that the time to execute the test will be as short as possible.

Another disadvantage of these methods is that a large sample of test-products and participants are needed to find all failures in the product. This is caused by the random customer selection of the test participants. Here is the strong point of the HCCT method that testing with only extreme customers and products will reduce the number of test participants and products. The problem is the determination of the right contrast factors for the selection of these extreme customers. For a better understanding of the contrast factors and to improve the test, it is important to know what customers expect from a new product and how they will use the product. Early prediction of customer requirements is therefore necessary. This can be achieved with methods as QFD and FMEA, because these methods can already carried out in the concept phase of the product development process.

Especially the QFD method is suitable for finding critical customer requirements. In the QFD approach is tried to identify what the customer wants or expects of the new product and translate these wants to product specifications. If critical customer requirements are known early, also contrast factors can be defined.

As the focus is on finding hard failures it is important that the (extreme) user that participate in the test will find as much hard failures as possible. Therefore it may be useful to test in a similar way as in the AST approach, which is focussed on finding hard failures only. In the stress tests only certain aspects (stressors) of a product are tested. In the situation of HCCT this can be done by letting the customers test only a specific functions or features of the product. When the extreme customers are selected for a certain product feature or function, their extreme usage may lead to finding more hard failures.

5.5.4 Conclusion

Since an answer is given to the sub-questions, an answer to the main research question can be provided. The main research question was:

How to improve the applicability of the High Contrast Consumer Test for the detection of hard failures?

As can be concluded from the answers on the sub-questions, one of the drawbacks of the HCCT method is that it is not clear how to define the critical contrast factors for the test. The QFD method can be used for defining critical customer requirements. So with the QFD approach it might be possible to make a better indication of relevant contrast factors.

However these contrast factors need to be chosen in such way that they are contributing to the detection of hard failures. In the case of high-end television relevant factors can be the frequent use of a certain function of the television, like teletext for example, or use of a large number of peripheral equipment.

If contrast factors and extreme users are selected for only specific functions or features of a product it may be likely that more failures can be found in that certain area of the product because this function or feature is extended to extreme usage.

The conclusion is that improvement for HCCT for the detection of hard failures can be achieved by usage of the QFD approach for the detection of critical customer requirements and better selection of contrast factors for the selection of extreme customers for the test. Also testing of only certain aspects (stressors) of the product by extreme users may improve the detection of hard failures.

Chapter 6: Conclusions and recommendations

In this chapter the conclusions of this research are described. In the first paragraph for each of the research questions the main conclusions are summarized. Furthermore, some recommendations for further research are presented.

6.1 Conclusions

Nowadays, market trends as high time-to-market pressure and increasing customer demands it is important to gather information about the product as early as possible in the PDP. Drawbacks of field feedback are that the gathering of information is to slow and the quality of the data is poor. Therefore it is necessary to prevent reliability problems in a pro-active way early in the PDP. Consumer tests are a way to shorten the feedback loops and enhance the quality of information. The regular consumer tests use random customers to test the products. But it is unlikely that all failures in a product will be found when 'normal' customers test 'normal' products. Therefore the High Contrast Consumer Test (HCCT) is developed. The method uses high contrasting 'extreme' customers and 'extreme' products for the test. This should leads to some advantages of the method, like a shorter period that is needed for the test and less test (prototype) products and test persons are needed.

However there are also some drawbacks of the method. It is not exactly clear in what way 'extreme' customers and 'extreme' products should be selected and what contrast factors should be used for the test. The focus of HCCT is mainly on finding soft failures. As in the Trader project the focus is mainly on finding hard failures, the goal of this research project was to provide an improvement of HCCT for the detection of hard failures.

Therefore the main research question was formulated:
How to improve the applicability of the High Contrast Consumer Test for the detection of hard failure?

First is investigated if there are hard failures to be found in an innovative high-end consumer electronics product after market introduction. Therefore an experimental test is conducted with a high-end LCD-television that had recently been introduced to the market. The conclusion that can be drawn from this test is that there are still hard failures in the product that has already been introduced to the market.

In the second part of the research is investigated how the HCCT method can be improved for the detection of hard failures. Therefore three research sub-questions were formulated. The conclusions that can be drawn from the answers to these questions are mentioned here.

How to find hard failures?
A number of different test methods that are commonly used in the product development process are reviewed. All the different test methods that are described in paragraph 5.2 can be used to find hard failures.

What are the strong and weak points of HCCT?
To know where improvement for the HCCT is needed, the strong and weak points of the HCCT method are analysed. A strong point of HCCT is that the method, because of using extreme and high-contrasting consumers and products for the test, a larger number of failures can be found. As a result HCCT also needs less test persons and products. Therefore the test can be executed in a short period of time.
But HCCT has some disadvantages.
- The method is mainly used to find soft reliability problems during the unpacking, installation and first use of the product.
- The selection of relevant contrast factors is not clear

What test methods can be applied to improve HCCT's capacity for finding hard failures?
The answer of this research sub-question provides for a large part the answer to the main research question. The main conclusions that can be drawn are:

Although all the described test methods are capable for finding hard failures, it is necessary that consumers can participate in the test. Therefore only the test methods prototype testing (hardware test), beta testing (software test) and usability testing (consumer tests) seem to be useful for improvement. However, these methods have drawbacks. They are time consuming and need a large number of test products and test participants to find failures.

A problem with HCCT is the definition of contrast factors for the selection of extreme customers. When a reliable estimation is made of the critical customer requirements early in the product development process a better definition of these contrast factors. Especially the QFD method is suitable for finding critical customer requirements in an early stage of the product development process.

Another improvement of HCCT that can be made is testing only specific functions of features of the product. When extreme customers are selected for testing only specific parts of the product their extreme usage may lead to finding more hard failures. This approach is similar to the AST method where also only certain aspects (stressors) of the product are tested.

6.2 Recommendations for future research

This last paragraph provides some recommendations for future research that result from this research.

- The suggestions for improvement that are stated in this thesis have to be examined more in depth. It has to be investigated how the methods like QFD should exactly be applied in the consumer test.

- More research is needed on how to define the right contrast factors and extreme consumers of high-end televisions, and for HCCT testing in general.

- As new innovative products are containing more complex software, research on the applicability of software testing, like software reliability engineering should be recommended.

References:

[Bas03]   Baskoro, G., Rouvroye, J.L., Brombacher, A.C., Radford, N., *High Contrast Consumer Test: a Case Study*, 2003.

[Ber00]   Berden, T., Brombacher, A.C., Sander, P., *The building bricks of product quality: an overview of some basic concepts and principles*, International Journal of Production Economics 67, pg. 3-15, 2000.

[Boe03]   Boersma, J., Brombacher, A.C., Loke, G., Loh, H.T., Lu, Y., *Reducing product rejection via a High Contrast Consumer Test*, 2003.

[Bro96]   Brombacher, A.C., *Predicting reliability of high volume consumer products: Some experiences 1986-1996*, Symposium "The Reliability Challenge", organised by Finn Jensen Consultancy, London, 1996.

[Bro05]   Brombacher, A.C., Sander, P.C., Sonnemans, P.J.M., Rouvroye, J.L., *Managing product reliability in business processes 'under pressure'*, Reliability Engineering and System Safety 88, pg.137-146, 2005.

[Bus90]   *Cost of non-quality*, Business Week, april 30, 1990.

[Esi04]   Strouken, L., Seeverens, H., Beenker, F., *Trader Project Plan – Television related architecture and design to enhance reliability*, Embedded Systems Institute, july 2004.

[Gra01]   De Graef, M.R., et al., *Betrouwbaarheid van technische systemen, anticiperen op trends*, STT 64, Den Haag, 2001 (in Dutch).

[Lew96]   Lewis, E.E., *Introduction to reliability engineering*, 2nd edition, John Wiley & Sons Inc., New York, 1996.

[Lov05]   Loveland, S., Miller, G., Prewitt Jr., R., Shannon, M., *Software Testing Techniques: Finding the defects that matter*, Charles River Media Inc., Hingham, Massachusetts, 2005.

[Luy99]   Lu, Y., Loh, H.T., Ibrahim, Y., Sander, P.C., Brombacher, A.C., *Reliability in a time-driven product development process*, Quality And Reliability Engineering International 15, 427-430, 2000.

[Luy00]   Lu, Y., Loh, H.T., Brombacher, A.C., Den Ouden, E., *Accelerated stress testing in a time-driven product development process*, International Journal Production Economics 67, pg. 17-26, 2000.

[Luy02]   Lu, Y., *Analysing reliability problems in concurrent fast product development processes*, PhD thesis, Eindhoven University of Technology 2002.

[Lyu96]   Lyu, M.R., *Handbook of Software Reliability Engineering*, McGraw Hill, 1996

[Mol02]   Molenaar, P.A., Huijben, A.J.M., Bouwhuis, D., Brombacher, A.C., *Why do quality and reliability feedback loops not always work in practice: a case study*, Reliability Engineering and System Safety 75, 295-302, 2002.

[Mus80]   Musa, J.D., *Software Reliability Measurement*, Journal of Systems and Software 1, pg. 223-241, 1980.

[Mus04]   Musa, J.D., *Software Reliability Engineering: More Reliable Software Faster and Cheaper*, 2nd edition, Authorhouse, 2004.

[Nie93]   Nielsen, J., *Usability Engineering*, Academic Press, San Diego, 1993.

[Oud04]   Ouden, E. den, Lu, Y., Ganesh, N., Geudens, W., *A customer-focused reliability approach*, 2004

[Oze99]   Ozer, M., *A Survey of New Product Evaluation Models*, Journal of Product Innovation Management, vol. 16, pg. 77-94, 1999.

[Pet00]   Petkova, V.T., Sander, P.C., Brombacher, A.C., *The use of quality metrics in service centres,* International Journal of Production Economics 67, 27-36, 2000.

[Pet03]   Petkova, V.T., *An analysis of field feedback in consumer electronics industry*, PhD thesis, Eindhoven University of Technology, 2003.

[Pet04]   Petkova, V.T., Lu, Y., Ion, R.A., Sander, P.C., *Designing reliability information flows*, Reliability Engineering and System Safety xx, 1-9, 2004.

[Por04]   Porter, A., *Accelerated Testing and Validation*, Elsevier Inc., Oxford, 2005.

[Rog03]   Rogers, E.M. (2003), *Diffusion of innovations*, 5th edition, The Free Press, New York, 1st edition in 1962.

[San00]   Sander P.C., Brombacher, A.C., *Analysis of quality information flows in the product creation process of high-volume consumer products*, International Journal of Production Economics 67, 37-52, 2000.

[Uit04]   Uitdenbogaard, T., *Classification of soft reliability problems for innovative products*, MSc thesis, Eindhoven University of Technology, 2004.

[Ulr00]   Ulrich, K.T., Eppinger, S.D., *Product design and development*, Irwin McGraw-Hill, 2000.

[Ver95]   Verschuren, P., Doorewaard, H., *Het ontwerpen van een onderzoek*, Lemma, Utrecht, 1995 (in Dutch).

[Whe92]   Wheelwright, S., Clark, K, *Revolutionizing product development: Quantum leaps in speed, efficiency and quality,* New York, Free Press, 1992.

[Wijt05]   Wijtvliet, K.G.C., *Exposing soft reliability problems by positioning consumers the better way,* MSc thesis, Eindhoven University of Technology, 2005.

[Won88]   Wong, K.L., *Off the bathtub onto the roller-coaster curve*, Proceedings Annual Reliability and Maintainability Symposium, IEEE, New York, 1988.

[Web1]   http://www.isixsigma.com/dictionary/

[Web2]   http://www.softwareqatest.com/

[Zai95]   Zairi, M., *QualityFunction Deployment: A main pillar for successful total quality management and product development*, International Journal of Quality & Reliability Management, vol. 12, pg. 9-23, 1995.

Appendix 1: Test product

PHILIPS 32PF9956/12
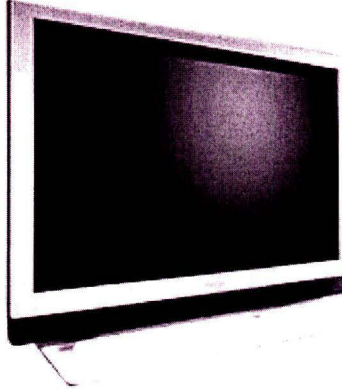
32 inch (82 cm) Pixel Plus Flat-TV

Superior picture quality with Pixel Plus technology and stunning design

Experience the ultimate flat TV with premium picture quality from Pixel Plus and the latest LCD display technology, packed in a stunning design

The Digital Media Reader enables to play multimedia-memory cards

Breathtaking natural pictures
High definition LCD WXGA display resolution 1366 x 768p
Pixel Plus technology delivers more vivid details
Digital Natural Motion produces smooth, judder free images
Active Control with Light Sensor optimises picture quality
Progressive Scan for extremely sharp and still images

Superb sound reproduction
Virtual Dolby Surround for a cinema-like audio experience
Integrated subwoofer with wOOx-technology for low bass

Multi-purpose convenience
1200 page Hypertext for instant fast access to teletext

Advanced connectivity
Modern top-quality HDMI-connectivity

Picture / Display
Aspect ratio : 16:9
Brightness : 450
Contrast ratio (typical) : 800:1
Diagonal screen size (inch) : 32
Diagonal screen size (metric) : 80 cm
Display screen type : LCD WXGA Active Matrix TFT
Picture enhancement : Pixel Plus, Digital Crystal Clear, Progressive scan, 3D combfilter, Active Control & Light sensor, Digital Natural Motion, Jagged line suppression,
Screen enhancements : Anti reflection coated screen

Viewing Angle (Horizontal) : 170

Viewing angle (Vertical) : 170

Panel resolution : 1366 x 768p

Response time (typical) : 12 ms

Supported Display Resolution

Computer formats : 640 x 480, 60HZ

Video formats : 640 x 480i - 1Fh, 640 x 480p - 2Fh, 720 x 576i - 1Fh, 720 x 576p - 2Fh

Sound

Sound enhancement : Auto volume leveller, Digital signal processing, Dynamic bass enhancement, Graphic equaliser, Smart sound

Sound system : Virtual Dolby Surround

Output power (RMS) : 2x15W

Loudspeakers

Built-in speakers : 4

Loudspeaker types : Dome tweeter, Integrated woofers with wOOx

Multimedia applications

Memory card access : Multi-slot

Memory card types : Compact Flash, Compact Flash type II, Memory Stick, Microdrive, MMC, Secure Digital, Smart Media

Multimedia-connections : Device from USB 1.1- memory type

Play format : JPEG-pictures, MP3

Convenience

Ease of installation : Auto programme naming, Automatic Channel Install (ACI), Automatic Tuning System (ATS), PLL digital tuning, Plug & Play

Ease of Use : Back lighted side controls, Delta volume per preset, Program list, Smart picture control, Smart sound control

Electronic Programming Guide : NexTView 3

Remote control type : RC4304/01

Picture-in-Picture: Text Dual Screen

Teletext : 1200 page hypertext

Teletext enhancements : Habit watch, Program information line, Word search

Remote control : Multi functional

Screen format adjustments : 6 widescreen modes, Auto format, Subtitle and heading shift

Clock : Smart clock

Child Protection : Child lock & parental control

Connection enhancement : Easy link

Tuner / Reception / Transmission

Tuner bands : Hyper band, S channel, UHF, VHF

TV system : PAL, SECAM

Video playback : NTSC, PAL, SECAM

Aerial input : 75 Ohm coaxial (IEC75)

Connectivity

Ext 1 Scart : Audio L/R, CVBS in / out, RGB

Ext 2 Scart : Audio L/R, CVBS in / out, RGB, Y/C

Ext 3 Scart : Audio L/R, CVBS in

Ext 4 : HDMI

Side : CVBS in, Headphone out, S-Video Y/C

Other connections : Analogue audio left / right out, Centre speaker connection in, SP-DIF in (coaxial), SP-DIF out (coaxial), Subwoofer out

Power

Power consumption : 165 W

Standby power consumption : <1

Mains power : AC 220 - 240 V +/- 10%

Ambient temperature : +5 -/+ 40 C

Dimensions

Colour cabinet : Pearl white silver (11092)

Product Depth : 107 mm

Product Height : 610 mm

Product Width : 875 mm

Product weight : 20 kg

Weight incl. packaging : 32 kg

Accessories

Included accessories : Table top stand, Wall mounting bracket

Optional accessories : Floor stand, Table top stand with swivel

Appendix 2: Usability techniques

The usability techniques can be divided in three categories: *inquiry, inspection* and *testing.* For all the different methods in each category a short description is given.

Inquiry
These are methods that gather information as a system is in use, either by observation of the user, or by asking the user to comment.

Field Observation
Observing users in the field is often the best way to determine their usability requirements. Traditional usability testing, while providing a laboratory environment that makes data collection and recording easy, also removes the user and the product from the context of the workplace. Sometimes, it's best to see exactly how things are done in the real world, to understand how the users are using the system to accomplish their tasks and what kind of mental model the users have about the system [Nie93].
This technique is best used in the early stages of development, when you need to know more about the issues surrounding the use of a product rather than actual metrics. In the really early stages of development, when you just have an idea that you might need a product to satisfy this particular need, field observations help gather user requirements and issues for incorporation into preliminary designs [Nie93].

Focus Groups
This is a data collecting technique where about 6 to 9 users are brought together to discuss issues as input to the design process. Typically the goal is to understand the users' work processes and goals and gather functional and usability requirements for a product A human factors engineer play the role of a moderator, who needs to prepare the list of issues to be discussed beforehand and seek to gather the needed information from the discussion. This can capture spontaneous user reactions and ideas that evolve in the dynamic group process [Nie93]. However, focus groups provide only "self-reported" opinions; because focus groups do not enable us to observe the behaviour of users performing actual tasks, they should not be the sole source of user data [Ted05].

Interviews
Interviews can be used in specification and evaluation. Interviews are a simple way of obtaining information from individuals concerning their opinions and subjective preferences. There are essentially two types of data that may be obtained from the above type of interview procedure. Use of an interview schedule comprising a structured questionnaire in the form of rating scales enables quantitative analysis of the data, whereas any additional questions can be used to refine and clarify the reasons why respondents hold a particular view. Interviews are used to examine an end user's subjective preferences concerning systems, as they are a simple, quick and effective means to obtain information concerning such issues as general acceptability, ease of use and comfort of use.
Use of interviews to obtain information requires some skill, and ideally interviewers should be trained in the use of such techniques. Interviewing users about subjective preferences can be carried out at all stages of the design process, from requirements definition at a product's initial conception to comparative evaluation of one or more final products [Sta05].

Logging Actual Use
Logging involves having the computer automatically collect statistics about the detailed use of the system. It is useful because it shows how users perform their actual work and because it is easy to automatically collect data from a large number of users working under different

circumstances [Nie93]. Of course there are ethical issues involved such as privacy and anonymity [Cut05].

Typically, an interface log will contain statistics about the frequency with which each user has used each feature in the program and the frequency with which various events of interest (such as error messages) have occurred. Statistics showing the frequency of use of commands and other system features can be used to optimize frequently used features and to identify the features that are rarely used or not used. Statistics showing the frequency of various error situations and the use of online help can be used to improve the usability of future releases of the system by redesigning the features causing the most errors and most access for online help. This technique can be used at the test or deployment stages of software development [Cut05].

Proactive Field Study

Before designing a system, in order to understand the users, their tasks, and their working environment, human factors engineers go to representative users' workplace and talk to them, observe them work, and ask them questions, to understand the user characteristics, the work flow, the system features they need, etc. This technique should be used during the requirement or early design stage of software development. This should be the first step of usability work for a project [Nie93].

Questionnaires

Many aspects of usability can best be studied by simply asking the users. This is especially true for issues to the users' satisfaction and possible anxieties, which are hard to measure objectively. Questionnaires are also a useful method for studying how users use systems and what features they particularly like or dislike.

From a usability perspective, questionnaires are an indirect method; since they do not study the user interface itself but only users' opinions about the user interface. You cannot always take user statements at face value. Data about people's actual behaviour should have precedence over people's claims of what they think. Be aware that there may be a big difference between what users say and what they do [Nie93].

Inspection

These are all variations on Review, walkthrough and inspection techniques, with specialised checklists or specialist reviewers.

Heuristic evaluation

A heuristic is a guideline or general principle or rule of thumb that can guide a design decision or be used to critique a decision that has already been made. Heuristic evaluation, developed by Jakob Nielsen and Rolf Molich [Nie93], is the most popular of the usability inspection methods of a system using a set of relatively simple and general heuristics [Use05]. The general idea behind heuristic evaluation is that several evaluators independently evaluate a system to come up with potential usability problems. It is important that there are several of these evaluators and that the evaluations are done independently. Heuristic evaluation is done as a systematic inspection of a user interface design for usability. The goal of heuristic evaluation is to find the usability problems in the design so that they can be attended to as part of an iterative design process. However, as the method relies on experts, the output will naturally emphasize interface functionality and design rather than the properties of the interaction between an actual user and the product [Usa05a].

Cognitive Walkthrough

Cognitive walkthrough involves one or a group of evaluators inspecting a user interface by going through a set of tasks and evaluate its understandability and ease of learning. The input to the walkthrough also includes the user profile, especially the users' knowledge of the task domain and of the interface, and the task cases. The evaluators may include human factors engineers, software developers, or people from marketing, documentation, etc. This technique

is best used in the design stage of development. But it can also be applied during any other stage of design using a prototype, or the final product [Usa05b].

Feature Inspection
Feature inspection is a usability inspection technique that identifies the tasks that a user would perform with an application and the features of the application that would be used to perform those tasks. Each feature is then evaluated for whether it is understandable, useful, and actually available to the user when needed. This approach emphasizes the importance of functionality to achieve usability. This approach also avoids feature creep by emphasizing the appropriate set of features and by prioritizing them in the critical tasks [Usa05b]. Feature inspection is best used in the middle stages of development when the functions of the product are well known [The05].

Pluralistic Walkthrough
At the design stage, when a prototype is available, a group of users, developers, and human factors engineers meet together to step through a set of tasks, discussing and evaluating the usability of a system. Group walkthroughs have the advantage of providing a diverse range of skills and perspectives that enables a greater number of usability problems to be found. As with any inspection, the more people are looking for problems the higher the probability of finding problems. Also, the interaction between the team during the walkthrough helps to resolve usability issues faster [Bia94].

Scenario-based Checklists
The inspection is done along three scenarios: novice use, expert use, and error handling. For each scenario, a checklist is provided that describes the issues to be checked, along with an instruction of the inspection process. Each inspector works on only one scenario. Usually three inspectors are needed for the inspection of a system, each for one of the three scenarios. But one inspector can also use this technique by carrying out three inspection sessions, each for one of the three scenarios. Inspectors can be human factors engineers or software developers. During the test the testers are available to assist participants if they get stuck, but such assistance is recorded as a task failure.
One moderator (a human factors engineer) is needed to prepare the inspection materials (user profile, task cases), arrange the inspection and collecting inspection results. This technique can be applied during the following development stages: design, production and ramp-up [Aus05].

Testing
These are techniques, which help the user and the usability tester/analyst to discuss/discover how the user is using and thinking about the system

Co-discovery Learning
A synonym for Co-discovery learning used in literature is Constructive Interaction. During a usability test, two test users attempt to perform tasks together while being observed. They are to help each other in the same manner as they would if they were working together to accomplish a common goal using the product. They are encouraged to explain what they are thinking about while working on the tasks. Compared to thinking-aloud protocol, this technique makes it more natural for the test users to verbalize their thoughts during the test [Nie93]. This technique can be used in the following development stages: design, production and ramp-up.
Co-discovery is also a technique used in learning. By having learners work on products together, they learn from each other and avoid having as many problems with computer skills getting in the way of solving the significant problem they are addressing [Usa05b].

Coaching Method
This technique can be used for usability test, where the participants are allowed to ask any system-related questions of an expert coach who will answer to the best of his or her ability. Usually the tester serves as the coach. One variant of the method involves a separate expert user serving as the coach, while the tester observe both the interaction between the participant and the computer, and the interaction between the participant and the coach. The purpose of this technique is to discover the information needs of users in order to provide better *training* and *documentation*, as well as possibly redesign the interface to avoid the need for the questions. When an expert user is used as the coach, than the expert user's mental model of the system can also be analyzed by the tester [Nie93].

Performance Measurement
This technique is used to obtain quantitative data about test participants' performance when they perform the tasks during usability test. This will generally prohibit an interaction between the participant and the tester during the test that will affect the quantitative performance data. It should be conducted in a formal usability laboratory so that the data can be collected accurately and possible unexpected interference is minimized. The results can be used to certify that a system or a product meets certain usability goals or to compare different competing products [Cid05]. Quantitative data is most useful in doing comparative testing, or testing against predefined benchmarks. The technique can be used in combination with retrospective testing, post-test interview or questionnaires so that both quantitative and qualitative data are obtained. The technique can be used in the following development stages: production and ramp-up [Nie93].

Question-Asking Protocol
During a usability test, besides letting the test users to verbalize their thoughts as in the thinking aloud protocol, the testers prompt them by asking direct questions about the product, in order to understand their mental model of the system and the tasks, and where they have trouble in understanding and using the system. This is a more natural way than the thinking-aloud method in letting the test user to verbalize their thoughts [Usa05b].

Remote Testing
Remote testing technique is used when tester(s) are separated in space and/or time from the participants. This means that the tester(s) cannot observe the testing process directly, and that the participants are usually not in a formal usability laboratory. There are different types of remote testing, like same-time but different-place and different-time different-place testing [Rex96].

Retrospective Testing
If a usability test session has been videotaped, the tester(s) can collect more information by reviewing the videotape together with the user participants and asking them questions regarding their behaviour during the test. So this technique should be used along with other techniques, especially those where the interaction between the testers and the participants is restricted. But using this technique means that each test takes at least two times as long. Another obvious requirement for using this technique is that the user's interaction with the computer needs to be recorded and replayed [Nie93].

Shadowing Method
During a usability test, the tester has an expert user (in the task domain) sit next to him/her and explain the test user's behaviour to the tester. This technique is used when it's not appropriate for the test user to think aloud or talk to the tester while working on the tasks [New05].

Teaching Method

During a usability test, let the test users interact with the system first, so that they get familiar with it and acquire some expertise in accomplishing tasks using the system. Then introduce a naive user to each test user. The tester will brief the novice users to limit their active participation and not to become an active problem-solver. Each test user is asked to explain to the novice how the system works and demonstrate to him/her a set of pre-determined tasks. This technique can be used for the following development stages: design, production and ramp-up [Vor95].

Think-aloud Protocol

Thinking Aloud protocol is a popular technique used during usability testing. During the course of a usability test, the test users are asked to verbalize their thoughts, feelings, and opinions while interacting with the system. Their ability (or lack of) to answer your questions can help you see what parts of the product interface were obvious, and which were obtuse. It is very useful in capturing a wide range of cognitive activities. You can use this technique in any stage of development. Thinking aloud is a cheap way of getting a lot of good qualitative feedback during testing. Two variations of thinking-aloud protocol technique are used [Nie93]:

- Critical response: This requires the user to be vocal only during the execution of certain predetermined subtasks.
- Periodic report: This is used when the task is complex and makes it difficult for users to think aloud while performing the task at the same time. The user, therefore, verbalizes at predetermined intervals of time and describes what he/she is currently trying to achieve. The length of the interval depends upon the complexity of the task. This technique is very time consuming, so it is recommended for subdivisions of a task.

References:

[Aus05]   Ausweb, Web Usability Testing, http://ausweb.scu.edu.au/aw2k/papers/osterbauer/paper.html.

[Bia94]   R. Bias "The Pluralistic Usability Walkthrough: Coordinated Empathies, in J. Nielsen & R. Mack "Usability Inspection Methods", pg.63-76, John Wiley, 1994.

[Cid05]   CID Usor, Performace Measurement, http://sunrize.nada.kth.se/usor/jml.cgi/Methods/performance.jml?graphics=true.

[Cut05]   Cutshall, T., Introduction to Usability Testing, http://www.arches.uga.edu/~cutshall/edit8350/usability/methods.html#quest.

[New05]   New architect, Stalk, your user, http://www.webtechniques.com/archives/2001/06/veen/.

[Nie93]   Nielsen, J., Usability Engineering, Academic Press, Boston, 1993.

[Rex96]   Rex Hartson, H., et. al., Remote Evaluation: The Network as an Extension of the Usability Laboratory, in CHI96 Conference Proceedings, Chicago, 1996

[Sta05]   Stakes, Interviews, http://www.stakes.fi/include/1-7-5.htm.

[Ser05]   Serco Usability Services, Usability requirements: how to specify, test and report usability, http://www.usability.serco.com/prue/requirements.htm.

[Ted05]   Ted-Ec Inc., Focus Groups, http://www.teced.com/ue-fg.html.

[Tes05]   Testing Standards working Party, Usability Guidelines, http://www.testingstandards.co.uk/usability_guidelines.htm.

[The05]   The Usability Company, Resources,
            http://www.theusabilitycompany.com/resources/glossary/feature-
            inspection.html.

[Usa05a]   Usability Net, Tools & Methods,
            http://www.usabilitynet.org/tools/expertheuristic.htm.

[Usa05b]   Usability first, Methods, http://www.usabilityfirst.com/methods/index.txl.

[Use05]   Useit.com: Jakob Nielsen's Website, Heuristic evaluation,
            http://www.useit.com/papers/heuristic/.

[Vor95]   Vora, P., Helander, M., "A Teaching method as an alternative to the
            concurrent think-aloud method for usablity testing", in Y. Anzai, K. Ogawa
            & H. Mori "Symbiosis of Human and Artifact", pp.375-380, 1995.

Testing Methods	Description	Stage	Usability Issues covered			Quantitative Data collected	Conducted remotely	Problems with method
			Effectiveness	Efficiency	Satisfaction			
Field Observation	Tester explore usability field	Ramp-up	Yes	No	Yes	No	No	• Difficult to visit participants at home
Focus Groups	Users are brought together to discuss product	Ramp-up	Yes	No	Yes	No	No	• Hard to analyse • Low validity
Interviews	Interviewer interviews user or test participant	Any	Yes	Yes / No	Yes	Yes	Yes	• Time consuming • Hard to analyse and compare
Logging Actual Use	Automatic collection of field usage	Ramp-up	Yes	Yes	No	No	Yes	• Mainly used for software development
Proactive Field Study	Designers explore the field to obtain user requirements	Requirement and Design	No	No	No	No	No	• Difficult to obtain future customer requirements
Questionnaires	Questionnaires filled in by user or test participant	Any	Yes / No	Yes	Yes	Yes	Yes	• Pilot work needed to prevent misunderstandings
Heuristic evaluation	Participants discover separately usability problems	Design, Production and Ramp-up	Yes	Yes	No	No	Yes	• Does not involve real users • Does not find unknown users' need
Cognitive Walkthrough	Group of participants test product	Design, Production and Ramp-up	Yes	No	No	No	No	• Does not involve real users
Feature Inspection	Participant test product features	Design, Production and Ramp-up	Yes	No	No	No	Yes	• Does not involve real users
Pluralistic Walkthrough	Users and developers discuss and evaluate product	Requirement	Yes	No	Yes	No	No	• No real prototype is available
Scenario-based Checklists	Designer test product with pre-defined scenario	Design, Production and Ramp-up	Yes	Yes	No	No	Yes	• Does not involve real users • All customer requirements have to be known in advance
Co-discovery Learning	Two-participants collaborate	Design, Production and Ramp-up	Yes	No	Yes	No	No	• Neither is an expert
Coaching Method	Participant can ask an expert questions	Design, Production and Ramp-up	Yes	No	Yes	No	No	• In reality, no coach is present • Not good for evaluation of a product

Performance Measurement	Tester or software records usage data during test	Design, Production and Ramp-up	Yes	Yes	No	Yes	No	• No qualitative data
Question-asking Protocol	During test, tester ask participant questions	Design, Production and Ramp-up	Yes	No	Yes	No	No	• Cognitive overload
Remote Testing	Tester and user are not co-located during test	Design, Production and Ramp-up	Yes	Yes	Yes	Yes	Yes	• The evaluator is not there • Cannot observe facial expressions
Retrospective Testing	Tester reviews videotape with participant	Design, Production and Ramp-up	Yes	Yes	Yes	Yes	No	• Extremely time consuming
Shadowing Method	An expert user explains the behaviour of the participant	Design, Production and Ramp-up	Yes	Yes	No	Yes	No	• Difficult to obtain
Teaching Method	Expert user teaches novice user	Design, Production and Ramp-up	Yes	No	Yes	No	No	• Neither is an expert
Think-aloud Protocol	Participant talks during test	Any	Yes	No	Yes	No	No	• Unnatural for participants • Cognitive overload

Appendix 3: Overview of test methods

	Failures types (hard/soft)	Test coverage	Position in PDP	Impact of changes	Test type	Test duration	Environment	Test persons	Number of test-products	Product/ customer selection criteria
Hardware tests										
QFD	Hard/soft	Critical customer requirements	Concept	Low impact Easy to make design changes	Analysis	Time consuming	Lab/office	User/ experts	None	---
FMEA	Hard	Top 20% of corrective action issues represent 80% of potential problems	Concept, Development, Prototype	Low impact/ Easy to make design changes	Analysis	5-10% of development process	Lab/office	Experts	None	---
AST	Hard	Only certain aspects (stressors) tested	Development, Prototype, Pre-production	High impact	Verification	Relative quickly (few weeks)	Lab	Experts	For each stressor some products needed	Random
Prototype	Hard/soft	Large number of stressors tested	Prototype	High impact/ Expensive to make changes	Validation	Time consuming	Lab/home	User/ Experts	Large sample	Random
Software tests										
Unit test	Hard	Coding errors	Development	Low impact	Analysis	Weeks	Lab	Experts	Large sample	Random
Function Verification Test	Hard	Only failures of the tested function	Development	Low impact	Verification	Weeks	Lab	Experts	Large sample	Random
System Verification Test	Hard	Cooperation of the functions	Development, Prototype	Low impact	Verification	Weeks	Lab	Experts	Large sample	Random
Performance Verification Test	Hard	Interaction of software and hardware	Development, Prototype	High impact	Verification	Time consuming	Lab	Experts	Small sample	Random
Integration Test	Hard/soft	Broad coverage	Prototype	High impact	Validation	Time consuming	Lab (Near realistic)	User/ Experts	Small sample	Random
Beta test	Hard/soft	Broad coverage	Prototype	High impact	Validation	Time consuming	Home	User	Small sample	Random
Consumer tests										
Usability Testing	Hard/soft	40-80% of the problems	Development, Prototype	High impact	Validation	Few weeks	Lab/home	User/ Experts	Small sample	Random
HCCT	Hard/soft		Development, Prototype	High impact	Validation	Few weeks	Lab/home	User	Small sample	Extreme