

Qualification of Components and Equipment in a new Era

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Abstract

The development of component and equipment qualification procedures is described from a telecommunication perspective. Quality and reliability trends are reviewed to give a background to expected future qualification procedures.

The complicated and costly component qualification is the responsibility of the component manufacturer while the equipment manufacturer has to concentrate on the verification and qualification of his end product. The paper reviews verification activities necessary during both the design and the industrialisation phases.

The importance of a Total Quality Feedback is highlighted for the continuous product improvement process. The latest methods for field data analysis are reviewed and examples of field data analysis will be given.

Finally, reliability data based on extrapolation of qualification results and the conventional part count reliability predictions are compared with real field failure statistics. Field failure statistics from a large number of different printed circuit board types are analysed to draw conclusions on controlling factors on hardware reliability and its time dependence.

The qualification methods and principles likely to be used in the future are discussed, where some important methods like extreme stress testing, environmental life cycle analysis and the analysis of critical process parameter statistics may be used.

Introduction

By qualification is understood some form of acceptance or approval of a product against a certain set of given requirements. In this paper we will review trends in the qualification of electronic components and equipments. We will also take a look at the change in responsibilities that may take place between component suppliers, equipment manufacturers and the end users. Over the years several new methodologies and

supporting tools have evolved, some of which we will briefly describe here.

Examples will be given from the telecommunications world and applications, but most of the conclusions drawn here are thought to be of general nature and applicable in a wider sense. The review concentrates on the trends and principles and gives less information on detailed qualification methods. A good reference¹ for the technical development can be found in last years proceedings from Reliability Challenge -95 given by Dr W. Gerling.

The material presented here is based on the author's own experience from 30 years of quality/reliability work in different positions and does not necessarily represent a formal standpoint of Ericsson Telecom AB.

A view at the history of qualification

The 50's

Already some 40 years ago, the reliability of the new invention, the transistor, was of concern. Hermeticity problems, corrosion, degrading breakdown voltages etc were noticed and soon some forms of standard test procedures began to evolve. Reading through old minutes from that time shows that many important reliability areas were identified already by then.

The 70's

20 years later, in 1978, the author defined a quality specification for microcircuits that was rather comprehensive and defined the procedures for acceptance inspection and tests, periodical tests and qualification reappraisal tests. At that time plastic encapsulated microcircuits were not allowed for general use in telecom applications. Table 1 gives some details of that specification. It is worth noticing that the moisture contents in the cavity of microcircuits were addressed. Another area of concern was the risk of failures due to thermal fatigue of bond wires that were flexing due to current pulses. Things like this was specified in a clause addressing visual inspection of technology and appearance.

Examination or test	Test conditions/ failure def.	Inspection requirements
Moisture content in cavity	> 2000 ppmv of H ₂ O	8/1
Hermeticity	> 5*10 ⁻⁸ atm cm ³ /s	18/1
Resistance to soldering heat	350 °C, electrical tests	18/1
Temp. cycling+ damp heat	5*(-55/+125oC) + 56 days 40/93	18/1
Endurance life tests	1000h endurance test	38/1

Table 1. Some of the tests specified in 1978 for the qualification of hermetic microcircuits.

Most of the tests were referring to IEC standard procedures but the inspection requirements were adopted from manufacturing practice at that time. The small sample sizes did not really prove or even support the hope that the parts would demonstrate the required reliability later on in field. The tests only gave evidence that the manufacturer occasionally had a possibility to build parts that passed the tests but that the reliability was entirely depending on the process control and stability of his manufacturing line. In that sense this type of qualification specification was rather modern and resembles that of many Japanese companies that never specified large samples but also never allowed any faults. (Instead of 18/1 they specified 22/0).

The 90's

Our quality specification survived many revisions and has today (1996) revision L. Revision K was written by the author in 1991. Here the requirements have been strengthened to give support to some reliability estimate in line with required field performance. The specification now also addressed areas such as design for reliability, a required 20 year use life with non increasing failure rates, requirements on quality assurance systems and a quality improvement programme that values the improvement rate more than the quality level demonstrated at a specific point in time. Table 2 gives some samples of the reliability requirements used for qualification.

Examination or test	Test conditions/ failure def.	Inspection requirements
Moisture content in cavity	> 2000 ppmv of H ₂ O	3/0
Hermeticity	> 5*10 ⁻⁸ atm cm ³ /s	AQL 0,04%
Resistance to soldering heat	260 °C, electrical tests	8/0
Moisture endurance (Plastic)	85/85, 1000h or 130/85 96h	76/0
Endurance life tests	150 °C, 1000h test	76/0

Table 2. Some of the tests specified in 1991 for the qualification of hermetic and plastic microcircuits.

A zero failure criteria was incorporated in order to reduce the sample size and to give the feeling that we expect zero defects. Of course this is not statistically relevant but it might be motivated from a psychological point of view.

In this specification the life test is designed to demonstrate a 20 years life at normal operating ambients. For certain important components even more specific tests were defined to take into account the thermal resistance and power dissipation of each individual component type. Sometimes reliability qualification tests had to run for up to 5000h to demonstrate the required reliability, also on larger samples than above. Such tests were tedious and expensive to perform but gave a comfortable feeling about the field reliability of the device types qualified in that way.

One example is shown in figure 1. One device had been qualified by a 6000h life test to verify a 40 years life capability and to collect enough of component hours to ‘demonstrate’ a failure rate of less than 40 fits. A field study later on showed that there was a good margin to the goal and that the failure rate after 2 years was actually around 2 fits.



Figure 1. Field failure rate of a component that passed a qualification test for max 40 fits

The future

Obviously the trend can not continue so that test times and sample sizes will increase to infinity. To improve the quality, larger sample sizes are needed to verify that quality. At the end we would need to test every device instead of making use of them. The trend must go the other way. Here are some of the “buzz words” for the future:

- 1 We will increase stress, require faster and efficient tests and play with small numbers again.
- 2 There will be a continuing approach to modular designs and library qualifications
- 3 Processes will be fully characterized with respect to these modules and vice versa.

These items will be discussed in more details in the following.

What to Qualify in the future?

Individual product types

Full custom types of components will still need to be qualified as there would be little information to build an approval upon. This is especially true when a new design in a new process, possibly in a new package is introduced. Such ‘lonely wolves’ are of course to be avoided as much as possible.

The traditional type of component qualification is also likely to be used for quite some time also in future.

Component Families and Packages

Design for Reliability will ensure that whole component families can be qualified as a group. This will be verified by using stress-to-failure test methods.

Design of Experiments to characterise the product robustness throughout the process windows is already being used and will gain wider acceptance not only for components.

The equipment user tends to fully rely on the component manufacturer's "in-house" qualification and may instead pay more attention to tests related to his application or production environment.

Manufacturing Processes

Design of Experiments are already used today to determine useful and safe process windows and will continue to do so. The manufacturing processes will be statistically computer controlled and that includes also testing procedures.

Robustness tests are used to determine when the product really starts failing due to process variations outside the safe process windows. This applies not only to component manufacturers but also to equipment manufacturers.

Application qualification

The equipment manufacturer may formalise an application test to add to the component manufacturer's "inhouse" qualification. This is to focus on production problems that may relate to a 'grey zone' of unspecified characteristics.

Vendor Qualification

Technology level and standard

This evaluation is based on a technical review of one or more factories of interest. The review is not formal but rather technical in its nature. A recommendation is given by a technical expert in the relevant field. This area seems to be gaining in importance.

Quality system standard

The base for this assessment may be ISO 9001-9002. The trend is to rely on third party assessments for a quality system base approval. Nobody would like to see hundreds of ISO-inspectors per year walking around through a class 1, sub micron fab.

Commercial and financial standard

Important suppliers are often evaluated by the purchasing organisations from a financial and commercial point of view. This may be seen as a natural and normal part of their daily work.

Manufacturing fabs or lines (QML)

It seems as an equipment manufacturer only at rare occasions needs to visit the manufacturing sites of a component manufacturer, e. g. an assembly site. It may be justified in the case of a quality problem or when preparing the 'ramp up' of a new important volume product. Otherwise the trend is to leave the fab work to the vendor and avoid getting into a procedure that requires endless fab audits, reaudits and certificate writing.

One way of qualifying manufacturing lines is by doing it together with other industries as the QML concept describes. It can be recommended if properly arranged and performed.

It requires, though, a good deal of coordinating efforts and is not likely to become a common practice for the future.

Qualification of the Qualification Process?

One seemingly very smart way of reducing lots of own component and fab qualification work would be to develop such a relationship to the component vendor that you would be able to simply qualify his internal qualification process or system and let him do the job for you.

This is, as a matter of fact, what many small companies have been forced to do, anyway, due to lack of own resources for component qualification work. In that sense many small companies are ahead of large electronic group companies that always have been used to take care of many detailed reliability investigations on their components. Now large companies also find that the resources needed to continue traditional component qualification is difficult to motivate and more rational methods are being introduced.

The changing scene

The product flow from component processing to the field service of the finished electronic equipment goes through a number of distinct steps. Figure 2 tries to depict the change of interest or responsibility between the component manufacturer, the equipment manufacturer and the telecommunication operator that was used in this example.

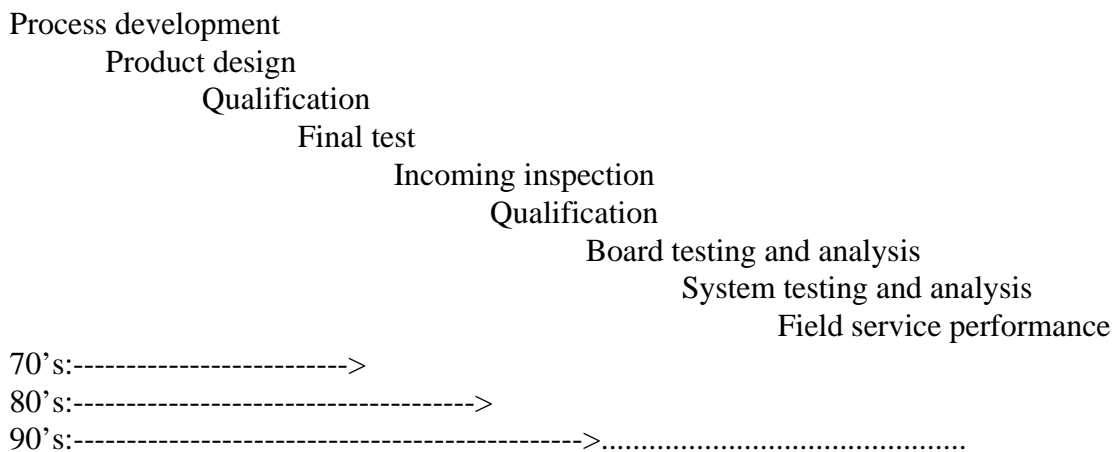


Figure 2. The component manufacturer is taking a wider quality responsibility and needs more of quality data feedback in order to cope with that responsibility.

At the beginning of the 80's, the component manufacturer developed the process, designed and verified the component, carried out lifetests and other qualification tests and screened the parts in his final test. The customer received the parts, performed his own qualification test and started then to inspect sometimes all 100% of the devices received. Then board assembly, test and system test followed before the delivery to the end customer. At site, the equipment was installed and retested again before the end customer could take over for acceptance test and put the equipment into field service.

During the 90's the improved quality made it possible to change this flow. The Vendor now become the main responsible for product qualification and his final test replaced the

incoming inspection at the equipment manufacturer. Instead a more rigorous application test took place and large efforts were given to build systems for quality data collection and analysis in the equipment manufacturer's own product flow.

Further possible changes

An equipment manufacturer must keep his eye on quality data. This will be dealt with further on under the heading Total Quality Feed back.

Areas of coming concern for qualification of components and equipment are e.g. regulations regarding EMC, environmental index and the potential of reusing or recycling components. As the reliability of used electronics and its components generally is very high it is likely that parts will be reused and not only scrapped for metal recycling. The qualification of components may include these aspects. A design review of a printed circuit board may include an evaluation of its possibility to be disassembled in an efficient and economic way.

Qualification Maintenance

After the initial qualification of a component family or a type of electronic equipment the question soon will arise: How to keep the qualification alive?

The most important point is to make sure that you have a good performance feedback system. See TQF later on.

In addition to that it may be advisable to collect and analyse information on the periodical tests that the component manufacturer is supposed to perform. This may seem as boring and tedious work, especially if the reports never contain anything but failure free sample tests.

A Quality Agreement may be one way to formalise the quality information exchange. But it is very important to:

- fulfil your part of the deal
- be active and give feedback
- be clear, define whom to report to and when
- arrange periodical management reviews of the agreement

An important electronic equipment needs to be evaluated periodically to verify that it still is a robust design having margins wide enough for both specification requirements and to the extremes of the application environments. Such tests may well be called requalification tests if it helps getting them done.



Total Quality Feedback (TQF)

The acronym TQF has been used as a project symbol for efforts to develop and strengthen our quality feedback systems at Ericsson Telecom AB. Basically the feedback ranges from collecting reliability information from the manufacturer, board testing results, system test results and to the collection and analysis of field failure statistics.

The most important part of the TQF loop is to make sure that the information is properly analysed and that improvement objects are identified, prioritized and initiated. A product or a component may become disqualified if its field reliability data deteriorates until the problem has been solved and the product is requalified again.

One efficient driving force for a successful improvement process is to assign proper and realistic failure costs to faults detected in different steps of the product's life cycle. The total failure costs per produced product may then be calculated, new goals defined and actions taken to reach these goals. This simple procedure has turned out to be very effective and is recommended to be used as a routine for future improvement management.

Qualification of Equipment

Robust design and robustness testing

The future electronic equipment is virtually failure free. As this is becoming an accepted concept the designers will not only verify their products against the specified limits. They will try to learn the real limits of their products, e. g. 'at what temperature does it really start failing?' .. voltage... frequency etc. Such robustness tests will also include investigations of both safe process windows and the margins to these windows that the product has been designed to. It will e.g. be natural to increase the soldering temperatures and times until faults appear and then to analyse what happened.

First customer application

Many times it is possible to let a customer be part of the qualification process of the finished product. New generations of telecommunications hardware or systems are often evaluated in a so called First Office Application, FOA. By this way it is also possible to get fast feedback on the functionality, ease of use etc that not always is specified in formal written documents. The cooperation with the end customers will increase considerably in the future. This is a natural consequence of the increased competition and the large number of new customers who have less "in house" technical experience.

Product qualification and volume ramp-up

Not only components but also equipment like printed circuit boards need to be formally certified or qualified. A certificate should state if the product has been qualified or not, and give reference to all relevant documents and reports forming the base for the qualification. As computer data bases are commonly available all members within a company might easily get access to detailed information about the qualification status and

background for almost any product or component they are using. At Ericsson we have today access to a world wide product information system that may give reference to such certificate details in the future.

The general trend for volume ramp-up times is that they get shorter. There will be less and less time for unstructured yield improvement actions. The yield race must be planned, structured, based on facts and clearly goal driven. Earlier experience will be fed back into the development phase to give benefit to the next development project.

As the product cycles, generally and in the telecom business, are becoming shorter and shorter it will be necessary to actively plan for the ramp down of older products to be replaced by better and more efficient ones. This may lead to some form of disqualification of older products not from a quality or reliability point of view but from a purely logistic one.

What reliability to qualify?

Must there be a failure rate?

For years we have been used to estimate equipment failure rates simply by adding the failure rates of the components inside of that equipment. Failure rate figures have been stored in databases making us believe that component failure rates are measurable characteristics like a delay time or similar. Figure 3 shows a scatter diagram on predicted and measured failure rates of components in field use. We do not get much help from this information.

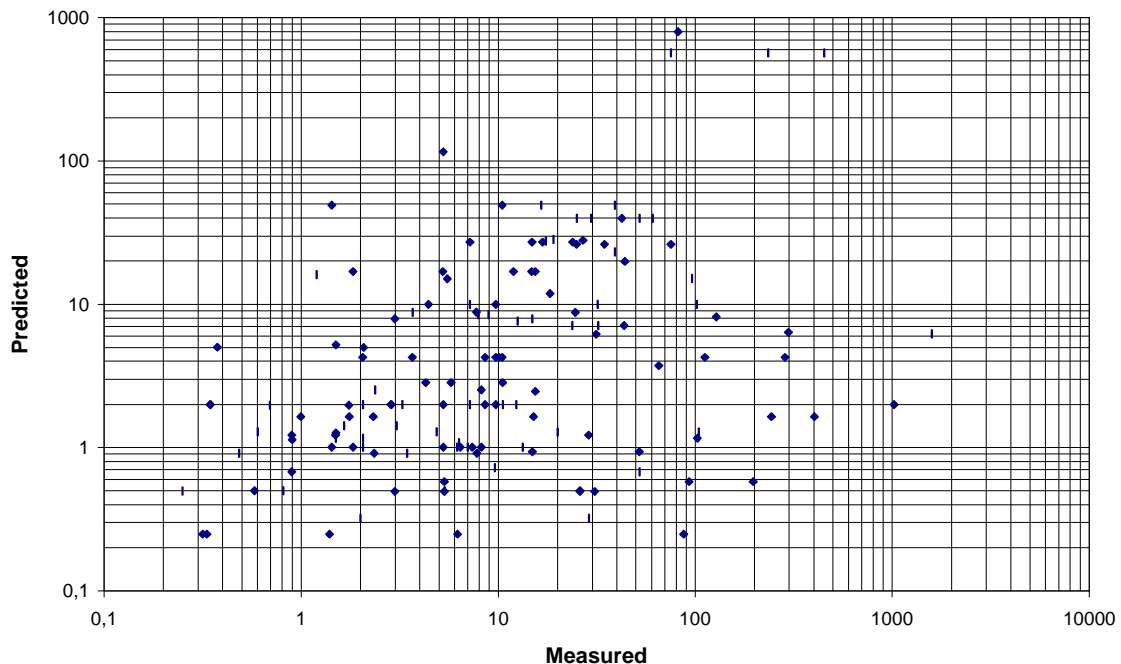


Figure 3. Measured and predicted field failures of components in a field reliability study.

Figure 4 shows a similar scatter diagram of measured and predicted failure rates of printed circuit boards based on part count prediction. Only large volume types of boards have been analysed and the number of returned boards was 13 or more to reduce the statistical variance.

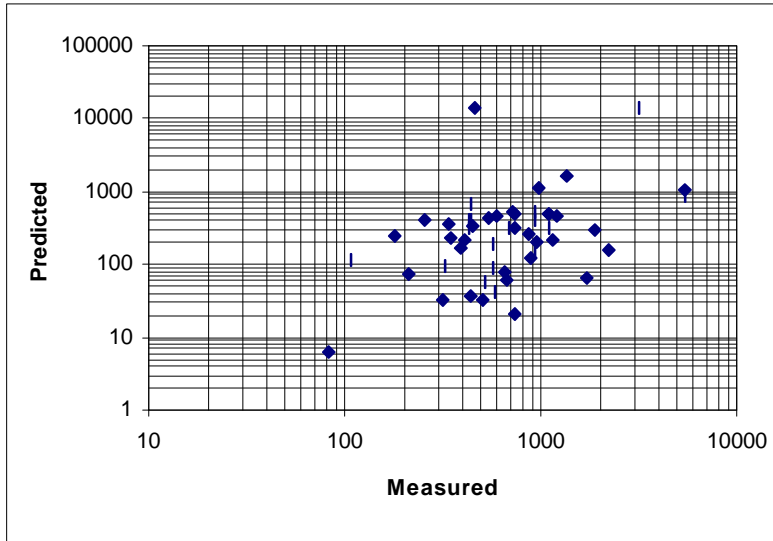


Figure 4. Measured and predicted failure rates (normalised) of printed circuit boards.

Why are products returned from the field?

There are several reasons as to why products are returned from field service. The return rate of telecom hardware is somewhat correlated to the seasons with a maximum during July-September due to thunderstorms. Component early failures may stand for 30% of board returns, an other 30% may be returned for no reason at all.

Is it possible to predict failure rates at all?

In addition to the part count method mentioned above, there are at least two other methods available.

One is simply to look at the reliability already demonstrated by similar products and to make the estimate based on that. This can only give a very rough estimate as it has been noticed that sometimes very similar products may have large variations in reliability. In this case it is recommended to use values at the lower end if there are several similar products to compare with. The reliability goals should always be aggressive.

An other way is to make use of already available test information. Several papers have pointed out that there is a correlation between yield and reliability but few of them have tried to quantify this correlation. In a recent study (still ongoing) we found that there is a useful correlation between the combined yield in board testing and system testing to the reported field failure % during the first year of use.

Figure 5 gives a correlation diagram where a linear combination of the failure levels in board testing and in system testing is used as the x-axis and the measured field returns during the first year is used as the y-axis. The values are normalised but give the right relations. The linear combination of failure levels from board and system tests was optimised by a computer program and gave the weight 5:1 between system tests and board test results.

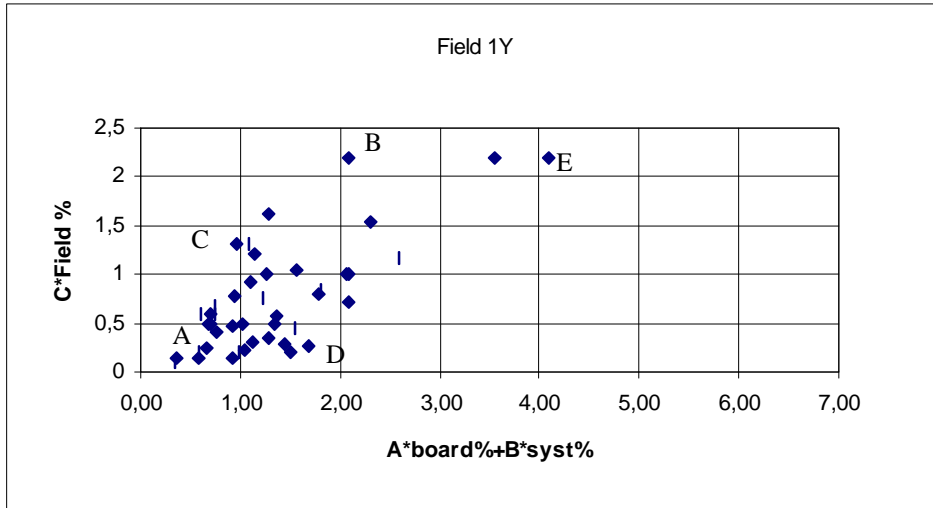


Figure 5. Correlation between test and field failures of a number of board types.

Such a diagram can be used to set reasonable goals for the reliability specification and qualification of new products. The diagram is also useful to identify products that can be classified as ‘reliable (A)’, ‘unreliable (B)’, ‘undertested (C)’, ‘possibly overtested (D)’ and ‘marginally designed (E)’.

Field performance - the final qualification

New products must be followed carefully during the first time in field service in order to detect any abnormal functionality or quality problem. In that sense the early field feedback gives the final qualification and should be part of the product certificate once a product review has been carried out, say six months after production ramp-up. At that time the corresponding field service statistics shall be collected, analysed and presented for the product team.

There are different methods available to perform this kind of field studies. I will here briefly refer to two of them, the non-parametric method and the parametric optimisation method.

The non-parametric method

This procedure requires that detail data about all failed products are available for the analysis. The exact number of products put into service at different points in time must be known. Each returned product must be traced back to its service location. The start time and the failure time for each product must be recorded and the accumulated failure level versus lapsed time must be normalised to the actual number of products at service at that time. The method is described in ref. 2 for the interested reader.

Due to the complicated data handling this method is in practice not often used. Therefore we have developed a new method that is easier to use and that does not require that detailed level of information.

The Parametric Optimisation method

EriView 2000 is the name of a new tool that has been developed for the analysis of field service data where the level of details available is not sufficient to run a non-parametric analysis. This method has earlier been briefly described in ref 3. The software is a heavy application in EXCEL and needs a fast computer to reduce iteration times.

The principle is simply to record the total number of products that are brought into service each time period (e.g. month, quarter or year). It is also necessary to record the total number of returned products from field service by each time period. The computer then tries to find a life distribution that gives the optimum fit to the reported number of returned products. This distribution is then used to calculate failure rates, MTTF and the accumulated level of failures vs field use time.

As an example we will illustrate the use of the TQF methods in an improvement project for reducing failure costs.

An improvement project

This project was started at the end of the qualification phase to make sure that the quality improvement was addressed aggressively enough to match projected ramp-up of production volumes. The project goal was simply to reduce the total failure costs by 50% within one year.

The first task was then to define the failure costs and to measure these. The second task was to analyse the available quality data, define corrective actions and to prioritize among them.

Failure costs were defined in four different areas: Board manufacturing and test, System testing, Installation tests at the customer's site and finally the failure costs due to field returns during the first year in service.

Figure 6 shows in normalised form the development of measured failure costs vs project time. It was also noticed that the field failure levels decreased at least partly due to reduced failure levels in the production line. Hence, the effect of quality improvements in a production line may be paid back twofolds due to the subsequently reduced field failure costs. This is also in line with the findings from figure 5.

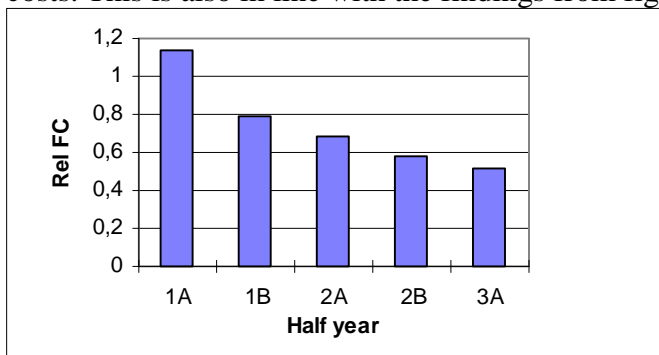


Figure 6. The reduction of failure costs per product vs time (normalised units).

Figure 7 gives an example of the field data analysis using *EriView 2000*. It shows the number of installed products per quarter, the number of returned products per quarter and the calculated number of returned products using a life distribution that gives the best fit to the data.

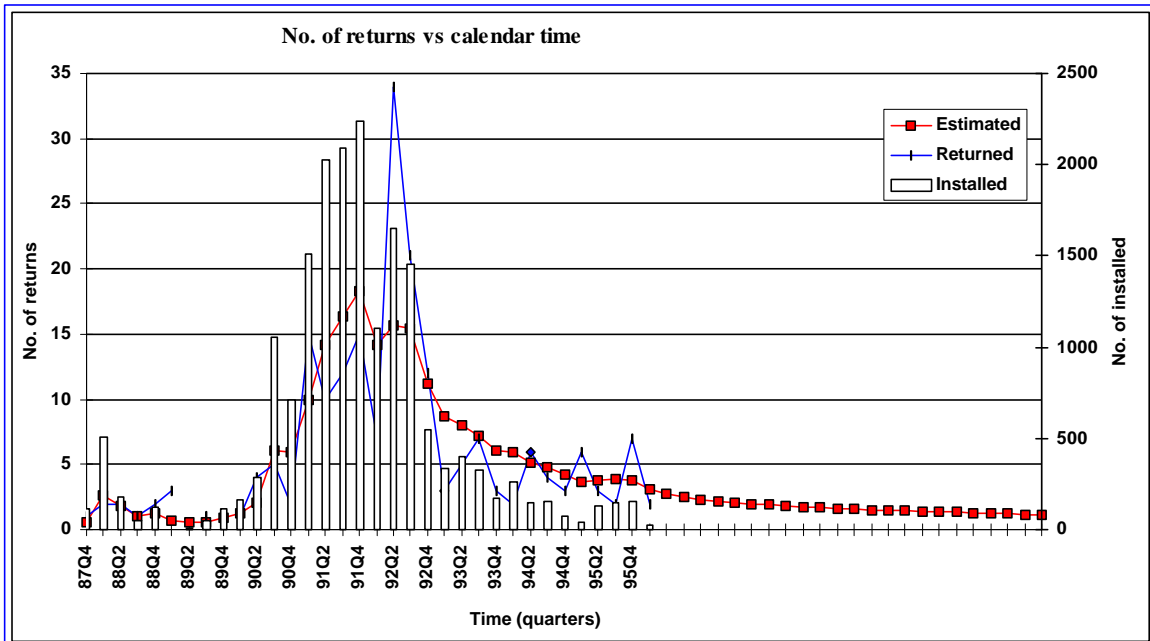


Figure 7. An example of field failure statistics including the calculated failures using an optimum fit life distribution.

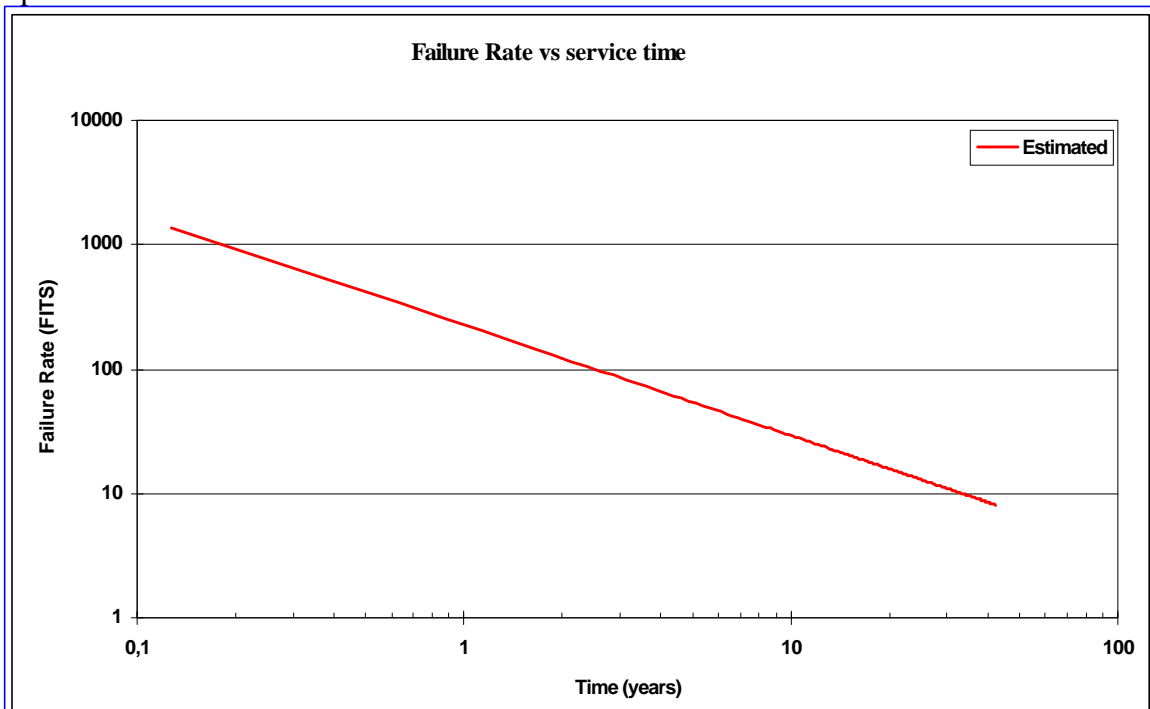


Figure 8. The failure rate (or return rate) vs field use time that gives the best fit to the reported field returns shown in figure 7.

Conclusions

The area of component and equipment qualification is continuously changing. Some of what has been brought up in this paper can be summarised in the following points:

- The trend is that component manufacturers will perform all necessary testing to give full confidence in the reliability characteristics of the components
- The equipment manufacturer needs to provide the component vendor with quality feedback and needs a Total Quality Feedback system to stay competitive in the long run.
- Process and product robustness design and tests will be necessary ingredients in order to continue product improvement.
- Reliability is not a physical characteristic like a thermal resistance unless we have a wear-out problem. It will be possible to design and manufacture virtually failure free products.
- The final qualification is given by the customer. Modern software tools make it easier to analyse field statistics for product follow-up and to get input to the continuous improvement.
- There seems to be a useful correlation between production test data and field reliability data.

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