BRITISH STANDARD

BS EN 61014:2003

Programmes for reliability growth

The European Standard EN 61014:2003 has the status of a British Standard

ICS 03.100.40; 03.120.01; 21.020

British Standards

National foreword

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The UK participation in its preparation was entrusted to Technical Committee DS/1, Dependability and terotechnology, which has the responsibility to:

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English version

Programmes for reliability growth
(IEC 61014:2003)

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(IEC 61014:2003)

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CENELEC

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Foreword

The text of document 56/859/FDIS, future edition 2 of IEC 61014, prepared by IEC TC 56, Dependability, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61014 on 2003-09-01.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2004-06-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2006-09-01

Annexes designated "normative" are part of the body of the standard.
In this standard, annex ZA is normative.
Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61014:2003 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 61703	NOTE	Harmonized as EN 61703:2002 (not modified).
ISO 9000	NOTE	Harmonized as EN ISO 9000:2000 (not modified).
ISO 9001	NOTE	Harmonized as EN ISO 9001:2000 (not modified).

CONTENTS

INTRODUCTION

Reliability improvement by a growth programme should be part of an overall reliability activity in the development of a product. This is especially true for a design that uses novel or unproven techniques, components, or a substantial content of software. In such a case the programme may expose, over a period of time, many types of weaknesses having design-related causes. It is essential to reduce the probability of failure due to these weaknesses to the greatest extent possible to prevent their later appearance in formal tests or in the field. At that late stage, design correction is often highly inconvenient, costly and time-consuming.

Life-cycle costs can be minimized if the necessary design changes are made at the earliest possible stage.

IEC 60300-3-5, Clause 1 refers to a "reliability growth (or improvement) programme" employing equipment reliability design analysis and reliability testing, with the principal objective to realize reliability growth. Reliability design analysis applies analytical methods and techniques described in IEC 60300-3-1. Reliability design analysis is of a particular value, as it allows early identification of potential design weakness, well before design completion. This allows introduction of design modifications that are inexpensive and relatively easy to implement without consequences such as major design changes, programme delays, modification of tooling and manufacturing processes. The reliability growth testing and environmental arrangements for the test part of this programme are essentially the same as those covered by IEC 60300-3-5, IEC 60605-2 and IEC 60605-3.

The importance of the reliability growth programme, integrated into the design or product development process, and known as integrated reliability engineering, is driven by limited time to market, programme costs and striving for product cost reduction.

Although effective for disclosure of potential field problems, a reliability growth testing programme alone is typically expensive, requiring extensive test time and resources, and the corrective actions are considerably more costly than if they were found and corrected in the early stages of design. Additionally, the duration of these tests, sometimes lasting for a very long time, would seriously affect the marketing or deployment schedule of the system.

The cost-effective solution to these challenges is a reliability growth programme fully integrated in both the design and evaluation phase as well as the testing phase. This effort is enabled by strong project management, by design engineering and often by customer participation and involvement. Over the past few years, leading industry organizations have developed and applied analytical and test methods fully integrated with the design efforts for increasing the reliability during the product design phase. This reduces reliance on formal and lengthy reliability growth testing. This technology is the basis for the integrated reliability growth strategy in this standard and will be discussed further in Clause 6. Some definitions and concepts are given first in order to lay the groundwork for discussing the integrated reliability growth methodologies.

PROGRAMMES FOR RELIABILITY GROWTH

1 Scope

This International Standard specifies requirements and gives guidelines for the exposure and removal of weaknesses in hardware and software items for the purpose of reliability growth.

It applies when the product specification calls for a reliability growth programme of equipment (electronic, electromechanical and mechanical hardware as well as software) or when it is known that the design is unlikely to meet the requirements without improvement.

A statement of the basic concepts is followed by descriptions of the management, planning, testing (laboratory or field), failure analysis and corrective techniques required. Mathematical modelling, to estimate the level of reliability achieved, is outlined briefly.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60300-1, *Dependability management – Part 1: Dependability management systems*[1]

IEC 60300-2, *Dependability management – Part 2: Guidance for dependability programme management*[2]

IEC 60300-3-1, *Dependability management – Part 3-1: Application guide – Analysis techniques for dependability – Guide on methodology*

IEC 60300-3-5:2001, *Dependability management – Part 3-5: Application guide – Reliability test conditions and statistical test principles*

IEC 60605-2, *Equipment reliability testing – Part 2: Design of test cycles*

IEC 60605-3 (all parts), *Equipment reliability testing – Part 3: Preferred test conditions*

IEC 60605-4, *Equipment reliability testing – Part 4: Statistical procedures for exponential distribution – Point estimates, confidence intervals, prediction intervals and tolerance intervals*

IEC 60812, *Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)*

IEC 61025, *Fault tree analysis (FTA)*

IEC 61160, *Formal design review*

IEC 61164, *Reliability growth – Statistical test and estimation methods*

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[1] Second edition to be published.

[2] Second edition to be published.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

NOTE 1 Certain terms come from IEC 60050(191) and, where this is the case, the concept from that publication is referenced in square brackets after the definition. ISO 9000:2000 is used as referenced to quality vocabulary.

NOTE 2 For analysis of the reliability growth test data, it is important to distinguish between the terms “failure intensity” (for repaired items) and “failure rate” or “instantaneous failure rate” (for non-repaired or one-shot items) defined in IEC 60050(191).

3.1
item
entity
any part, component, device, subsystem, functional unit, equipment or system that can be individually considered

NOTE An item may consist of hardware, software or both, and may also, in particular cases, include people.

[IEC 60050, 191-01-01]

3.2
reliability improvement
process undertaken with the deliberate intention of improving the reliability performance by eliminating causes of systematic failures and/or by reducing the probability of occurrence of other failures

[IEC 60050, 191-17-05]

NOTE 1 The method described in this standard is aimed at making corrective modifications aimed at reducing systematic weaknesses or reducing their likelihood of occurrence.

NOTE 2 For any item, there are limits to practicable and economic improvement and to achievable growth.

3.3
reliability growth
condition characterized by a progressive improvement of a reliability performance measure of an item with time

[IEC 60050, 191-17-04]

NOTE Modelling (projection) and analysis of reliability improvement during the design phase is based on the standard estimation of the expected product reliability within a given time period.

3.4
integrated reliability engineering
engineering tool, consisting of a multitude of reliability/dependability methods integrated into all engineering stages and activities regarding a product, from the conceptual phase through its use in the field by a combination of contributions from all relevant stakeholders

3.5
product reliability goal
reliability goal for a product based on certain corporate targets, market requirements or desired mission success probability that is reasonably achievable according to the past history and technical evolution

NOTE For some projects, the reliability goal is set by the customer. The product specific goal is the target value of the reliability growth process.

3.6
systematic weakness
weakness, which can be eliminated, or its effects reduced, only by a modification of the design or manufacturing process, operational procedures, documentation or other relevant factors, or by replacement of substandard components by components of proven superior reliability

NOTE 1 A systematic weakness often results in a failure that is related to a weakness in the design or a weakness of the manufacturing process or documentation.

NOTE 2 Repair or replacement (or re-run in case of software) without modification is likely to lead to recurrent failures of a similar kind.

NOTE 3 Software weaknesses are always systematic.

3.7
residual weakness
weakness, which is not systematic

NOTE 1 In this case, risk of recurrent failure of a similar kind is small or even negligible, within the expected test time scale.

NOTE 2 Software weaknesses cannot be residual.

3.8
failure
termination of the ability of an item to perform a required function

NOTE 1 After failure the item has a fault.

NOTE 2 “Failure” is an event, as distinguished from “fault”, which is a state.

[IEC 60050,191-04-01]

NOTE 3 The term “termination” implies that the product had the ability to perform a required function and then lost it. Once the system design is capable of meeting the specified performance requirement, then reliability failure is the termination of this capability.

3.9
failure mode
manner in which any system or component ceases to perform its respective designed operation

NOTE 1 A failure mode may be characterized by its frequency of occurrence or by probability of its occurrence to include into the system’s or component’s reliability.

NOTE 2 To address the reliability of a system, fundamentally its corresponding failure modes, the causes of these failure modes, and the frequency or probability of occurrence of these modes under the system’s intended use environment need to be addressed.

3.10
relevant failure
failure that should be included in interpreting test or operational results or in calculating the value of a reliability performance measure

NOTE 1 The criteria for inclusion should be stated.

[IEC 60050, 191-04-13]

NOTE 2 The criteria for inclusion are stated in 6.4.6.

3.11
non-relevant failure
failure that should be excluded in interpreting test or operational results or in calculating the value of a reliability performance measure

[IEC 60050, 191-04-14]

NOTE The criteria for classifying failures as not relevant are stated in 6.4.5.

3.12
systematic failure
failure that exhibits, after a physical, circumstantial or design analysis, a condition or pattern of failure that may be expected to cause recurrence

NOTE 1 Corrective maintenance without modification does not usually eliminate the failure cause.

NOTE 2 A systematic failure can be induced at will by simulating the failure cause.

NOTE 3 In this standard, a systematic failure is interpreted as a failure resulting from a systematic weakness.

3.13
residual failure
failure resulting from a residual weakness

Categories of failures observed in a reliability growth test programme

3.14
failure category A
systematic failure experienced in test for which management decides not to attempt corrective modification, due to cost, time, technological constraints or other reasons

3.15
failure category B
systematic failure experienced in test for which management decides to attempt corrective modification

NOTE Failure categorization is not applicable for reliability growth in the product design phase as the view on potential failure modes is entirely different. Here, all components could potentially fail in one mode or another, but the likelihood and consequence of such an event may be very different. Failure modes and their potential causes that may be highly likely to occur are addressed first, and, if resources and schedules allow, other failure modes, less likely to occur, are addressed. A product with a high number of components where each of those might have multiple failure modes, and each of the failure modes might have multiple causes, might require a great amount of effort to classify and then re-classify each of the failure modes or causes, too cumbersome and costly to justify the classification. As the failure classification does not add any value, it is not applied during the reliability growth effort in the product design phase.

3.16
fault
state of an item characterized by inability to perform a required function, excluding the inability during preventive maintenance or other planned actions, or due to lack of external resources

NOTE A fault is often the result of a failure of the item itself but may exist without prior failure.

[IEC 60050, 191-05-01]

3.17
fault mode
one of the possible states of a faulty item, for a given required function

[IEC 60050, 191-05-22]

NOTE The use of the term “failure mode” in this sense is allowed for identification of a potential item or component failure.

3.18
instantaneous reliability measure
reliability measure for an item at a given point (past or present) in a reliability growth programme

NOTE 1 The reliability measure used in design analysis is the expected product reliability in a predetermined time, or its equivalent failure intensity calculated from the assessed product reliability associated with a time period of interest.

NOTE 2 Occasionally, the reliability measure can be expressed in terms of equivalent MTBF or MTTF also calculated from the assessed product reliability associated with a time period of interest.

NOTE 3 Whenever time is used in this standard, it can be substituted by other counts such as cycles, distance travelled (miles, kilometres), or copies.

NOTE 4 In this standard, the term failure intensity is used for a reliability measure of a repairable system, but terms like failure rate, instantaneous failure rate, MTBF, or MTTF can be substituted as appropriate. Further, the system is assumed repairable unless specifically stated otherwise.

NOTE 5 The reliability measures for a system commonly used in test are the (instantaneous) failure intensity (IEV 191-12-04) or the mean operating time between failures (MTBF) (IEV 191-12-09) as well as the (instantaneous) failure rate (IEV 191-12-02) or the mean time to failure (MTTF) (IEV 191-12-07).

NOTE 6 Values of reliability measures are estimated by reliability growth models determined for product improvement in the design and the test phase separately.

3.19
extrapolated reliability measure
reliability measure for an item, predicted for a given future point in a reliability growth test programme, where the corrective modifications are promptly introduced throughout the programme

NOTE 1 The definition of the modifier "extrapolated" (IEV 191-18-03) applies here but is restricted to time.

NOTE 2 The previous test conditions and corrective modification procedures are assumed to continue unchanged.

NOTE 3 The value of the reliability measure is estimated by a reliability growth model applied to the previous data and the same trend is assumed to apply also to the future period of the programme.

NOTE 4 The reliability measures commonly used are the (instantaneous) failure intensity (IEV 191-12-04) or the mean operating time between failures (MTBF) (IEV 191-12-09) as well as the (instantaneous) failure rate (IEV 191-12-02) or the mean time to failure (MTTF) (IEV 191-12-07).

NOTE 5 Extrapolated reliability measure is not applicable for use in a reliability growth programme during the design phase.

3.20
projected reliability measure
reliability measure predicted for an item as a consequence of the simultaneous introduction of a number of corrective modifications

NOTE 1 The modifications are often introduced between two successive phases in the programme.

NOTE 2 The reliability measures commonly used in the formal reliability growth test are the (instantaneous) failure intensity (IEV 191-12-04) or the mean operating time between failures (MTBF) (IEV 191-12-09) as well as the (instantaneous) failure rate (IEV 191-12-02) or the mean time to failure (MTTF) (IEV 191-12-07).

NOTE 3 Reliability measure during reliability growth in the design phase is the product reliability projected for the time period of interest such as warranty period or mission duration.

NOTE 4 The values of these measures are estimated by a reliability growth model.

3.21
usage profile
detailed information on environmental and operational aspects, their levels and content, duration, and sequence, expected to be encountered in a new product

3.22
field performance report
summary and analysis of the field data pertinent to the product to be designed

3.23
product specification for reliability
description of expected product performance for the specified time period under the expected usage profile

3.24
reliability and life test
test (environmental or other stress) designed to prove or estimate probability of occurrence of failure modes or their respective causes when those estimates are difficult to make solely by analysis

NOTE Operational test (life testing) is carried out on a product to demonstrate reliability.

3.25
reliability growth planning
plan of reliability activities such as analyses, components and materials selection and testing that would assure increase in product reliability

NOTE The same term can also refer to planning of the magnitude and the quantity of design improvements necessary to attain the product reliability goal. This planning consists of an analytical representation of the course of reliability growth in design and gives an estimate of the number and magnitude of design changes (improvements) necessary to attain the reliability goal.

3.26
preliminary reliability estimates
estimates made for new product based on inherited design

3.27
preliminary reliability allocation
reliability apportioned to the parts of design where, because of the lack of information, preliminary estimates cannot be made

3.28
design guidelines
document with design rules that point out known design criteria for reliability enhancement

3.29
continuous design reliability assessment
updating reliability assessment of the new product concurrently with the design evolution and testing of components and subsystems

3.30
FMEA and failure mode mitigation
identification of critical and/or safety-related failure modes, their causes and effects and estimation of likelihood of their occurrence regarding product usage profile, and life

NOTE Mitigation addresses causes and effects of failure modes with high severity and probability of occurrence. A very useful tool in failure mode analysis of a design is found to be fault tree analysis, which is a logical representation of hardware and associated failure modes.

3.31
key components
those components, which are determined to be essential for the intended product performance and which are evaluated and selected on the basis of available and satisfactory reliability and environmental information

3.32
final reliability report
compilation of methods, analyses, tests, results, lessons learned, mitigated consequences of failure modes, critical components and findings on their reliability, achieved reliability growth and the final reliability estimate and evaluation of the confidence in the reliability and integrity of the product

NOTE The report archives the information to be used as a source of information, references, reports, and a starting point for the next version or similar product.

3.33
reliability assessment of product changes
evaluation of changes of components, design or manufacturing process on product reliability

NOTE The changes may result from corrective actions, cost reductions on products or changes in the production process.

3.34
continuing reliability testing
reliability testing on ongoing lot of production to verify that the product reliability has not been compromised by the manufacturing processes or a lot of components of inferior quality

3.35
FRACAS
failure reporting analysis and corrective action system, closed loop system for tracking and bringing design issues to closure

NOTE As a database, it is a source of information on test and field experienced failure modes on products related to the new design. The analysis may then address potential of existence of those failure modes in the design being analysed.

3.36
system
set of interrelated or interfacing elements

[ISO 9000:2000, definition 3.2.1]

NOTE 1 In the context of dependability, a system should have

a) a defined purpose expressed in terms of required functions; and

b) stated conditions of operation/use (see IEV 191-01-12).

NOTE 2 The structure of a system is hierarchical.

3.37
component
item on the lowest level considered in the analysis

3.38
allocation
procedure applied during the design of an item intended to apportion the requirements for performance measures for an item to its sub-items according to given criteria

3.39
integrated reliability growth
reliability growth achieved through joint efforts of analysis, testing, design engineering and other information and activities for identification and mitigation of potential item failure modes

3.40
intermittent failure
failure that may not be reproducible every time the item is tested for it and that appears sporadically

3.41
recurrent failure
failure that appears repetitively

3.42
action list
list prepared to outline actions necessary to be taken for achievement of reliability growth

3.43
condition or pattern of failure
manner in which some failures occur

3.44
circumstantial analysis
analysis of the circumstances in which some failures occur

3.45
equivalent failure rate
failure rate of a component or an item calculated from its achieved reliability for the corresponding time period with an assumption of a constant failure rate in the course of that time period

NOTE The obtained value of the equivalent failure rate is valid for the particular time period only.

4 Basic concepts

4.1 General

The basic concepts for reliability growth of a product are similar, whether the product weaknesses are discovered through design, analysis, or test.

In a programme of reliability growth design analysis, the product design is analysed to determine whether any of its components and their interactions constitute potential weaknesses when subjected to the expected operational and environmental stresses and their potential extremes. Results of the design analysis may be compared with the product reliability goals or requirements, and recommendations are made for the necessary improvements. Here, the design stress and component weakness analysis regarding their respective failure modes are instrumental for determination of potential failures, improvements and the reliability growth.

Design analysis should not be limited to electronics, as mechanical components and software are also subject to failure. For that reason, the appropriate reliability measure is the probability of survival or probability of failure, rather than the failure rate or failure intensity, as the mechanical components often cannot be related to a failure rate especially to a constant failure rate, but rather to a failure probability (wear-out).

All reliability analytical methods can be applied, including testing specifically designed to detect potential failure modes, especially those where the analysis would be too complex, or would be likely to produce uncertain results. Failure modes, or their causes, found to have a high probability of occurrence are addressed through design improvement, and the new design reliability is reassessed. In that manner, reliability growth is monitored and the progress is recorded. Design reliability analysis also includes imbedded software, as well as the hardware-software interactions.

In a programme of reliability growth testing, laboratory or field testing is used to stimulate the exposure of weaknesses and to improve the reliability of a system, module, sub-assembly or component. When a failure occurs it shall be diagnosed, repair and/or replacement shall be carried out and testing shall be continued. Concurrently with testing, past failures shall be analysed to find their basic causes and, where appropriate, corrective modifications shall be introduced into design or other procedures, resulting in progressive reliability growth. This procedure applies equally to pure hardware and to embedded software.

A reliability growth programme on non-repairable, or one-shot, items or component only shall provide for successively modified samples, each of a more reliable design than the one before.

4.2 Origins of weaknesses and failures

4.2.1 General

Weaknesses are normally unknown in product use until they are revealed by failures. However, a weakness may be created long before the occurrence of an observable failure by an unconscious human error in some operation affecting an item such as excessive operational or environmental stress, or inadequate component derating such that the component strength is inadequate to withstand the expected stress or combination of stresses. Alternatively, it may be inherent in a material or component due to a process not being under complete control.

4.2.2 Systematic weaknesses

Systematic weaknesses are normally related to product design, components selection, manufacturing process or similar procedures.

The number of types of weaknesses present is influenced by:

- accuracy of specification or estimation of environmental and operational stresses, or conditions of use (product usage profile);
- novelty, complexity or criticality of design, manufacturing processes or usage;
- constraints such as inadequate development or production time scales, stringency of finance, size, weight or performance;
- skill and level of training of personnel involved, especially design personnel;
- physical layout that may be a cause of component overheat or be a reason for manufacturing defects.

Systematic weaknesses can occur both in hardware and software and may have very wide effects because a single cause results in similar weaknesses being built into all items. Corrective modifications intended to eliminate systematic weaknesses or to reduce the likelihood of their occurrence may themselves include errors that introduce new systematic weaknesses.

Systematic weaknesses can relatively easily be identified by testing even small sample sizes since they occur in all or most of the systems. A precondition is, of course, that the test conditions stimulate the failure mode.

4.2.3 Residual weaknesses

Residual weaknesses are normally related to uncontrolled random variation of the item or of its components. The factors given in 4.2.2 also contribute to the incidence of residual weaknesses but this can be reduced by personnel training, the learning process and quality control.

Residual weaknesses are found only in hardware. Unlike systematic weaknesses, their effects are restricted to single items. A significant proportion of the residual weaknesses present in an item can generally be eliminated by reliability screening, but others remain and will result in failures at random intervals throughout the life of the item. Any extensive repairs, replacements or modifications involve the risk that new residual weaknesses may be introduced.

Residual weaknesses are very difficult to detect in testing, since they are found only in a small fraction of the systems. Large sample sizes can therefore be required. The best way to avoid residual weaknesses is mistake proofing, quality control (i.e. statistical process control) or adequate design margins. However, it has to be emphasized that the term random failures should be avoided. The time that the failure is observed may be random, but the cause of the failure is deterministic, even though we may not know the physical failure mechanism.

4.3 Basic concepts for reliability growth in product development process; integrated reliability engineering concept

In a programme of reliability growth during the product design phase, the product design is analysed to determine whether some of its components or their interactions constitute potential weaknesses when subjected to the expected operational and environmental stresses and their potential extremes. Results of the design analysis may be compared with the product reliability goals or requirements, and necessary recommendations made for the necessary improvements. Here, the design stress and component weakness analysis regarding their respective failure modes are instrumental for determination of potential failures, improvements and the reliability growth.

All reliability analytical methods can be applied for the reliability growth in the product design phase, including testing specifically designed to detect potential failure modes, especially those where the analysis would be too complex, or would be likely to produce uncertain results. Failure modes, or their causes, found to have high probability of occurrence are addressed through design improvement, and the new design reliability is reassessed. In that manner, reliability growth is monitored and the progress is recorded.

Design reliability analysis also includes imbedded software, as well as the hardware-software interactions. Qualitative reliability measures should also be followed during the design. An action list may be made consisting of identified but not thoroughly investigated risks and assumed but not evaluated failure modes, as well as known failure modes. The reduction in number and severity of items on this list may be followed as a reliability growth measure.

4.4 Basic concepts for reliability growth in the test phase

In a programme of reliability growth, laboratory testing or field-testing is used to stimulate the exposure of weaknesses and improve the reliability of a system, equipment, component, or similar item. When a failure occurs it shall be diagnosed, repair and/or replacement shall be carried out and testing shall be continued. Concurrently with testing, past test failures shall be analysed to find their root causes and, where appropriate, corrective modifications introduced into design or other procedures, resulting in reliability growth. This procedure applies equally to pure hardware and to embedded software.

Reliability growth in test is generally associated only with the reduction of the effects of systematic weaknesses. The sequence of events from the initial weakness to its elimination is shown in Figure 1 for both systematic and residual cases.

Decision on whether a test failure is category A or B is usually made as follows.

– Safety-related systematic test failures should always fall in category B.
– Systematic test failures that can be mitigated within reasonable technical, financial, and time constraints are also category B.
– Systematic test failures that are not safety-related and that would require a complex item re-design with a substantial cost and programme delays may be classified as category A failures.
– Test failures determined to be residual are classified as category A failures.

The decision-making team is usually composed of design, reliability, and programme management personnel.

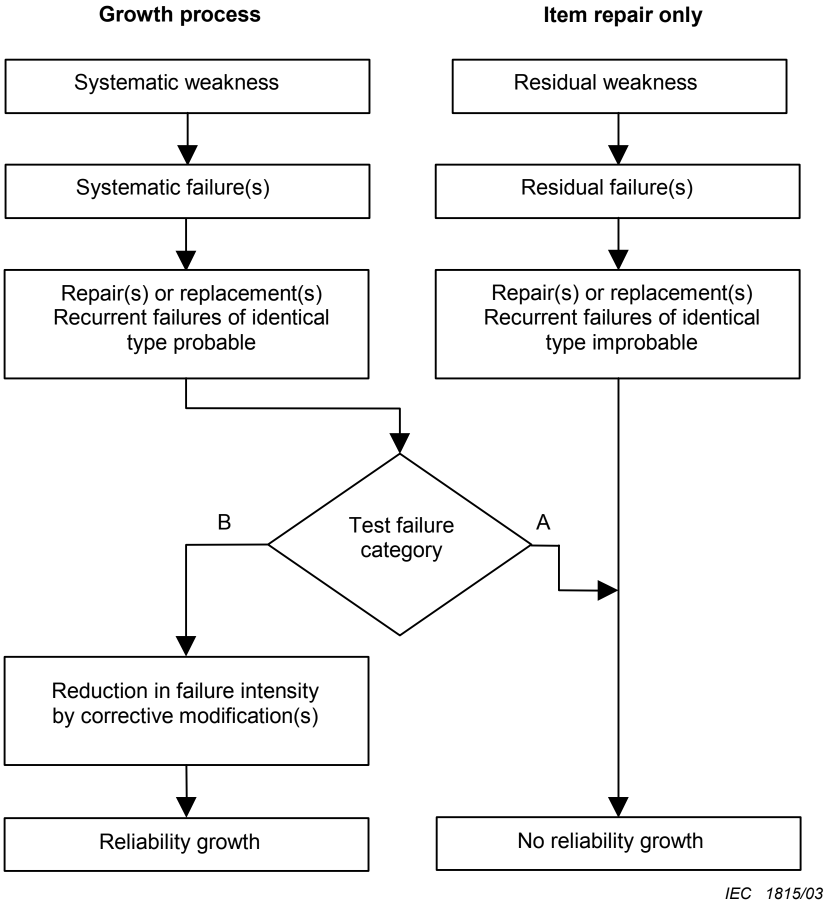


Figure 1 – Comparison between growth and repair processes in reliability growth testing

Extreme caution has to be exercised in classification of the modifications. It is often a tendency during reliability growth test programmes to declare a successful fix or a significant confidence in fix. It is of paramount importance to verify the fix in test, not only in the same test conditions in which the failure occurred, but also to bear in mind the contributing factors of the previous test environments. Another factor that also has to be examined with care is the possibility that the modification introduces a different failure mode, which may not appear in the remainder of the test. Additional testing for possible speculated failure modes of the fix may be a justified practice. It also has to be borne in mind that the modifications, no matter how successful they may appear, also have a failure rate contributing to the failure intensity of an item.

A reliability growth programme on non-repairable or one-shot items (expendable items, such as missiles) or components only, shall provide for successively modified samples, each of a more reliable design standard than before.

Reliability growth testing of software is independent of physical environment (for example, temperature and humidity) but may be affected by other environments (for example, use and maintenance) and is unaffected by reliability screening. However, estimates of reliability performance of software can be obtained only through observation of the software programmes in hardware, either test hardware or the real hardware, software code exercising, monitoring and recording of failures. Consequently, reliability growth of software is affected by the ability of performance testing to expose weaknesses during the programme. Such testing should therefore be as comprehensive as possible, in order to include all peculiar and unforeseen conditions, or combinations of conditions, which may arise in practical use.

4.5 Planning of the reliability growth and estimation of achieved reliability during the design phase

4.5.1 General

Since the failure intensity of the test object is reduced by every successful modification, methods of estimation of instantaneous failure rate, equivalent failure rate, failure intensity, probability of failure, or of MTBF, which assume constant failure intensity, are not valid during the growth process. However, at each point of introduction of the improvements, the concept of constant equivalent failure intensity (failure rate) may be valid.

This standard therefore outlines the principles of mathematical modelling for estimating the growth achieved and the projected reliability. Related techniques may be used in planning reliability improvement programmes by counting and estimating the number and the magnitude of the problems on the action list as well as design changes during the design process, or the test time required to reach a specified reliability goal.

4.5.2 Reliability growth in the product development/design phase

Estimation of reliability growth is relatively simple during the product development/design phase, as the design improvements are easy to estimate, and thus the resultant product reliability. Reliability growth planning in the design phase, however, is very similar to the reliability growth planning in the test phase. It involves keeping track of the number of activities on the action list and performing the required design changes during the duration of the design period to achieve necessary reliability growth. The similarity stems from the fact that the reliability growth by analysis and design improvement in the design phase follows the same pattern as the planned reliability growth test. This is because the fact that the potential failure modes – or their causes – that are the highest risk are addressed first. The analogy with the test experience is that the failure modes that are the most likely to occur are those that occur first. Thus, the failure modes are addressed chronologically according to their likelihood of occurrence and severity in design and test, resulting in similar mathematical modelling.

The reliability growth modelling here is based on the design improvements resultant from analysis; therefore, the model takes into consideration the number and the magnitude of design improvements during the design period. The result is a step line representing the reliability of the resultant equivalent failure rate. This curve can be approximated with a power line for the equivalent failure rate, in a similar way as is done for the reliability growth test programme.

Figure 2 shows an idealized plot for the planning of the reliability growth in the product design phase.

The x-axis in Figure 2 may be expressed in terms of time duration by measuring time to a design improvement. The total time is the duration of the design period.

Usually in the industry it is desirable to represent reliability and reliability improvement/ growths in terms of improvement in the probability of survival within a specified period such as warranty or mission. This is especially meaningful to the consumer industry where the percentage failed means the percentage of a product returned for repair within the warranty period. Improvement in the reliability measure is also very convenient for a product when there is a mixture of mechanical devices or structures and electronics. Planned reliability growth can be represented in a similar way as in Figure 2, except that the metric is the probability of survival as shown in Figure 3 (Krasich method – IEC 61164).

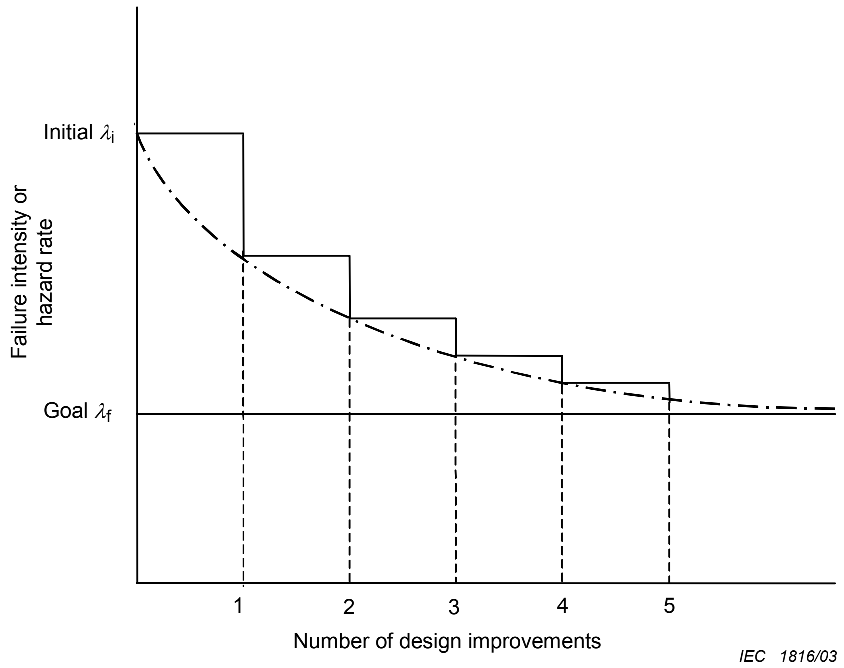


Figure 2 – Planned improvement (reduction) of the equivalent failure rate

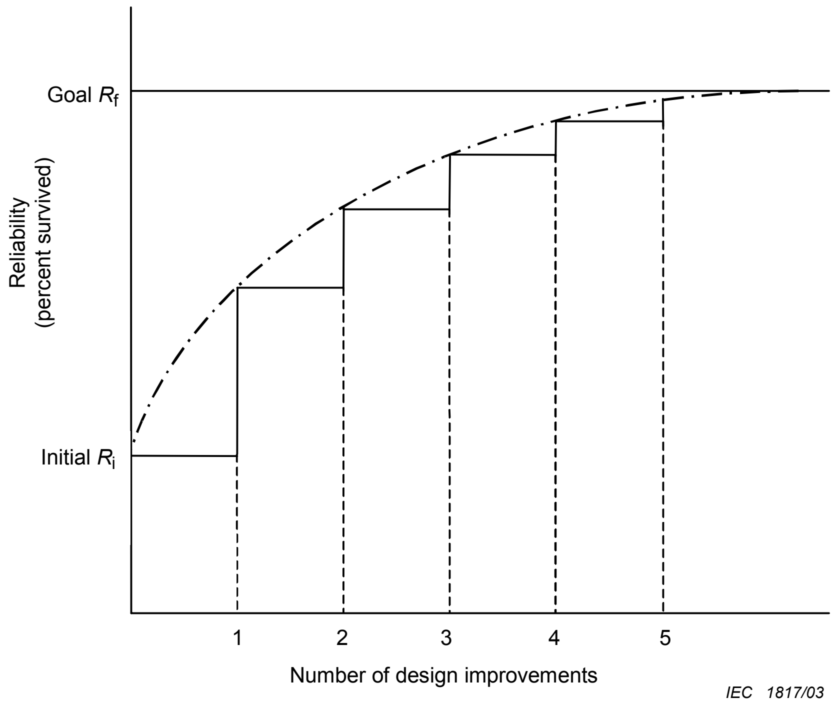


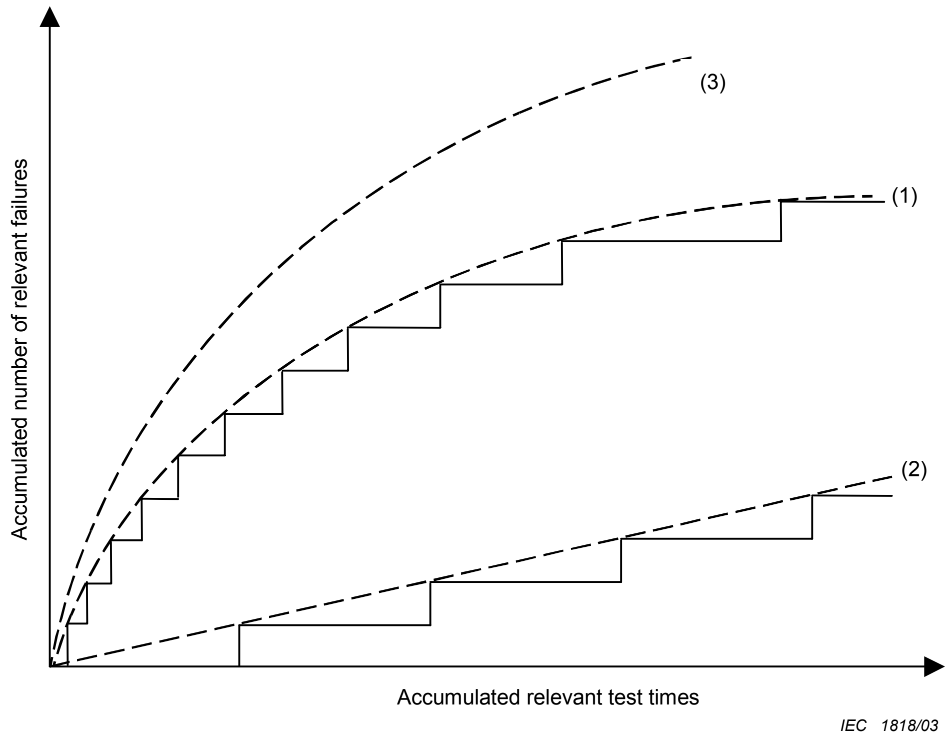
Figure 3 – Planned reliability improvement expressed in terms of probability of survival

4.5.3 Reliability growth with the test programmes

The accuracy of any test reliability evaluation method depends on how efficiently the test environment, monitoring procedures and failure reporting are controlled, and the testing time is recorded. In this respect, data from the laboratory are usually more dependable than those from the field or from "informal" test programmes.

The most influential factor in laboratory test is the assumed test sequence and environmental and operational stress levels, and their relationship to the use environment. Here, the appearance of failures is very dependent on the applied type and magnitude of stress; therefore, the failure rate calculations and the goodness of final reliability estimation is related to the goodness of the test design. For that reason, extreme care should be devoted to the accurate representation of real-life stresses (see IEC 60300-3-5, 6.3.2). Modelling should not be attempted if there is doubt about the degree of control. However, it is important to realize that, even if control is insufficient and modelling has to be abandoned, the processes of improvement described in this standard will always result in growth of reliability performance. A programme shall still be undertaken even if quantitative results cannot be estimated.

In Figure 4, characteristic (1) shows an idealized staircase plot of the accumulated number of the first failures due to each type of systematic weakness, against test time. This characteristic appears exponential in shape, reflecting the finite number of types of inherent systematic weakness to which the curve tends. Characteristic (2) is of residual failures against their time of observation. This characteristic appears linear in form, after the end of the early failure period. The sum of characteristics (1) and (2) gives characteristic (3), the total relevant failures, tending ultimately to linearity. Recurrences of similar types of systematic failure may appear if corrective modification is delayed or is ineffectual.



Key

Characteristic (1) First failure of each type of systematic weakness

Characteristic (2) Residual failures

Characteristic (3) Total of (1) and (2)

Figure 4 – Patterns of relevant test or field failures with time

The characteristics in Figure 4 depend upon the following assumptions.

- The early failure period is excluded; otherwise there would be non-linearity at the start of characteristic (2).
- No new types of weakness are included which were created during the period of the programme, such as might be introduced during repair or modification.
- No failures due to normal or acceptable wear-out are included.
- The environment, modes of operation and depth of testing remain constant throughout the programme. Any cycle in the test routine should be short and self-consistent.
- Test time is accurately monitored.

5 Management aspects

5.1 General

Management shall set up procedures for planning and executing a reliability growth programme and shall establish the important liaison links between the testing activity and those responsible for corrective modifications. Managerial guidelines are covered by IEC 60300-1 and IEC 60300-2.

With the high reliability requirements and short development times and market life times of products today, it is no longer possible first to design the product and then to test it for reliability. Therefore the confidence in the product design, components and manufacturing processes has to be built up gradually during the project. As the analysis and tests take place, potential problems and failure modes are identified, verified, analysed and solved (removed by design changes). This process is described in this standard. The classical concept of reliability growth, once the product has been released to the market or taken into use, is included in the reliability growth process, as described by this International Standard, but the main emphasis is now on the growth activities before production is started.

The reporting from the reliability growth process gives the management and, where required by contract, the customer a status for the reliability of the product at each project milestone, at each new design release, and for each preproduction prototype build. The report shall include a projection of the reliability into the future based on the analysis, test and improvement activities planned and based on the effect of such activities in previous projects. This projection allows early detection of a possible gap between the projected reliability and the target reliability for the product. In the case of a significant gap, it is then possible to add resources in time. However, it has to be emphasized that the projected reliability is based on the planned improvement activities and their previously shown effect. If the number of planned activities is reduced, for example, due to lack of time or resources, the projected growth cannot be expected.

Further, it should be noted that the activities that had a given effect in earlier projects will not necessarily have the same effect on the new project. For example, the technology, the project team or the project manager may have changed. In addition, the company has (it is to be hoped) learned from the earlier project. This means that the reliability at the start of the process can be expected to be relatively lower, but since the first failures are easier to remove than the last, the same effect cannot be expected, by the same activities in the new project.

5.2 Procedures including processes in the design phase

Figure 5 shows the management procedures diagrammatically.

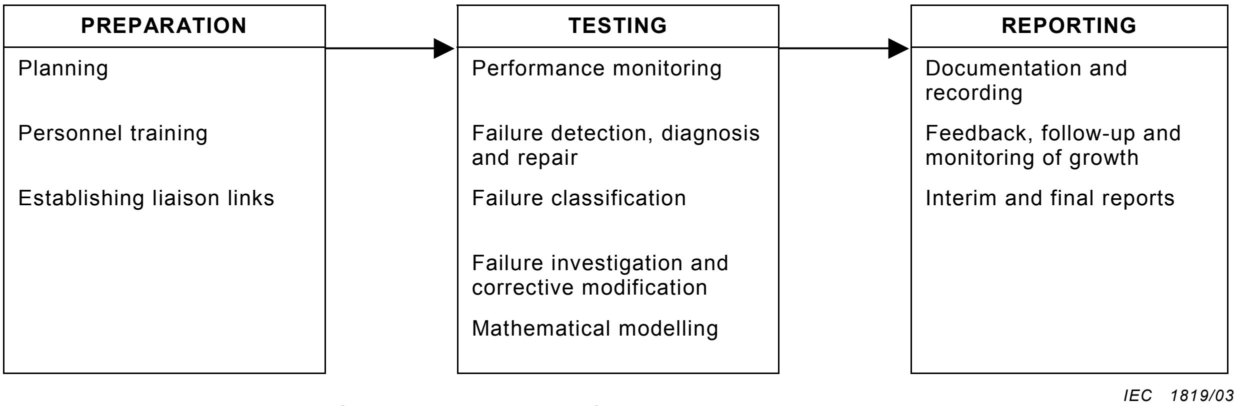


Figure 5 – Overall structure of a reliability growth programme

A period of preparation shall be scheduled for planning purposes (see Clause 6). This also allows all personnel to become acquainted with the equipment to be tested, and for both formal and informal liaison links between the testing and design activities to be set up (see 5.3). Testing requirements are detailed in 6.4, failure classification is detailed in 6.4.4 and corrective modification in 6.4.8. These three procedures are summarized in Figure 5.

Mathematical modelling for the reliability growth programme in the product development/ design phase can be commenced as soon as the knowledge about the initial product reliability is acquired and the project-specific reliability goal is set.

Mathematical modelling (see 6.4.9) for the dedicated reliability growth test programme should not commence until a statistically significant number of failures have occurred. Since estimation of growth is of less importance than the process of improvement, modelling shall be omitted if the model requirements are not fulfilled, rather than run the risk of giving misleading results.

Reporting of the failures experienced in test consists essentially of day-to-day detailed logging, feedback to design and reporting to the user. The elements of these activities appear in 6.4.12.

5.3 Liaison

Corrective modifications aimed at removing systematic weaknesses require a reliability engineer to progress them personally, since documentation alone will not trigger the necessary actions effectively. This engineer shall maintain close liaison with the personnel concerned with the various sources of failure information and with those responsible for elimination of systematic weaknesses.

The principal sources of failure data are as follows:

- supplier information;
- analysis and simulation;
- accelerated test and step-stress tests, highly accelerated life test (HALT);
- reliability improvement testing;

– reliability screening;
– reliability demonstrations;
– environmental qualification testing;
– acceptance testing;
– field trials;
– operational use;
– data from similar equipment.

Reliability improvement testing shall be regarded as the most significant source, since it is dedicated to this purpose and specifies close control of environment and data collection. However, other sources may provide useful background information in establishing failure categories, for example, data from similar equipment. A computer data bank with searching and sorting facilities enables similar types of failure from the various sources to be collated.

The areas of responsibility in which follow-up action may be needed include

– design and development;
– components suppliers and sub-contractors;
– drawing offices;
– specifications;
– production planning;
– manufacture;
– reliability screening;
– acceptance testing;
– technical manuals;
– operating and maintenance instructions;
– training;
– transportation and handling;
– users.

Figure 6 illustrates an example of the essential liaison links. Different suppliers may have different organizations and the personnel may have different or multiple responsibilities.

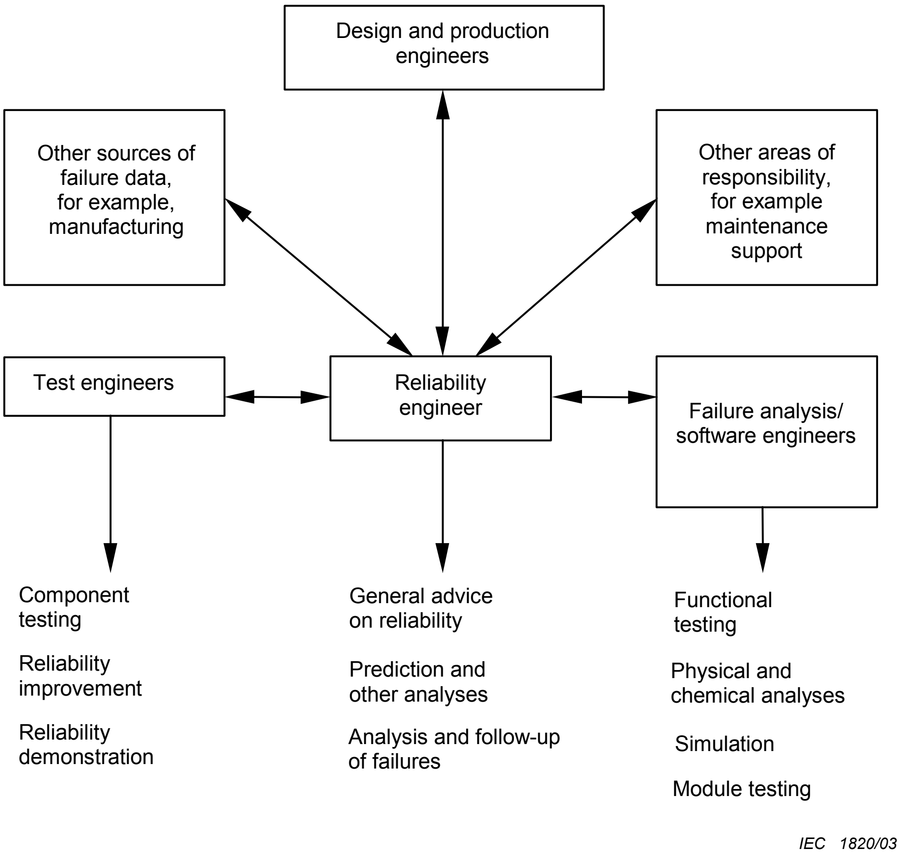


Figure 6 – Chart showing liaison links and functions

5.4 Manpower and costs for design phase

As the nature and scale of projects and items vary widely, only general guidance can be given. For small projects the reliability engineer indicated in 5.3 may be engaged only part-time on a project, while in other cases he may require considerable supporting staff.

The estimated manpower should allow both for the reliability engineer and for the design effort needed to follow up weaknesses, which would not have been known if there were no reliability growth programme. Analysis of failures and design of modifications may absorb significant effort in design and other appropriate areas.

Items to be tested and test equipment may afterwards be recoverable and may not contribute to the overall costs if they can be delivered or diverted to other uses after refurbishment. Unused spares may also be recoverable but may have to be reworked, updated to current revision or scrapped.

5.5 Cost benefit

An investment in a reliability growth programme may bring substantial savings over the life cycle of the total population of items.

These savings depend on many factors, including the size of the population of items (or of the elements subject to failure within an item), the length of the life cycle, the average repair cost and the investment in maintenance facilities in the field. Usually, a cost-benefit analysis will determine the cost effectiveness of a reliability growth programme.

A substantial addition to the cost savings comes from the fact that, during the design phase, in the case of design changes, there is no change in tooling, circuit board layout change, or change in the manufacturing process, for the changes made before these activities are finished.

6 Planning and execution of reliability growth programmes

6.1 Integrated reliability growth concepts and overview

A product, regardless of the intended application and its nature, normally evolves through several major phases. The product development phases depend on the individual suppliers' planning and product management structure. An example of product development general flow is as follows.

a) **Concept and requirements phase**

The product is conceptually defined, and the preliminary requirements are determined regarding its performance and expected life.

b) **Product definition**

The product is defined in more detail, and planning is done for its design, production, and marketing. Here, a preliminary architecture and preliminary engineering design are determined along with product functionality and operational characteristics (system design).

c) **Design**

The product is defined in detail regarding its functionality, structure, and all performance characteristics. The design is finalized based on engineering analyses and evaluations, and the design components are determined. At the end of this phase, the product is ready for production.

d) **Evaluation and validation test phase**

Concurrently with necessary preparations for regular production, the product is evaluated by test, for its performance and reliability. With the first production run, qualification and reliability testing of the product take place.

e) **Product field-use phase**

The last phase of the product is its use, when data collection on its performance takes place, and the appropriate data analysis provides information for further considerations and possible improvements of the next generations of the product or the parts of its design that would be inherited by another product.

In the course of each of the design process phases, a reliability activity, analysis or test, is taking place, each of these contributing to the product reliability growth, making it an integrated reliability growth process or integrated reliability engineering process.

The product development phases vary with each individual supplier and may bear different names. The example explained above and depicted in Figure 7 gives a general timeline when various reliability activities take place.

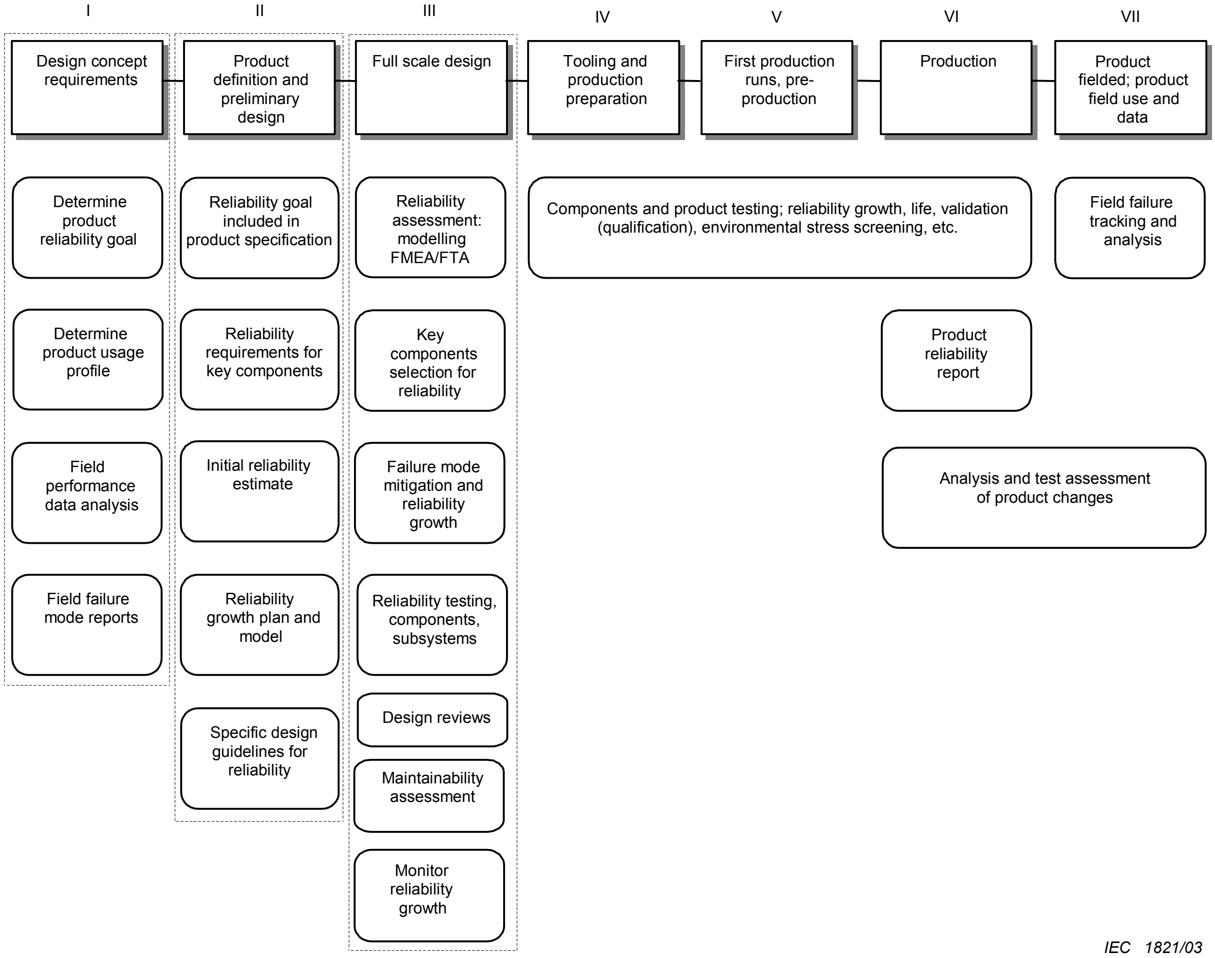


Figure 7 – Integrated reliability engineering process

6.2 Reliability growth activities in the design phase

6.2.1 Activities in concept and product requirements phase

The product specific reliability goal shall be set at the beginning of the programme based on reasonably achievable reliability through the product reliability growth programme during its design phase. The goal shall be set taking into account the following:

– for consumer products, reasonable assumptions of tolerable percentage return for service in the product warranty period;

– for military (defence) products, the mission scenario and expected performance that is dictated by the product designed and its designated use.

This activity is not limited to the determination of numerical or descriptive reliability goals or requirements. It is essential to determine what the product functions are, and also to determine all conditions and levels of acceptable operation. This is to evaluate and define what constitutes a system critical failure, degraded performance, or minor operational anomaly. It is to be expected that the definitions of failures or degraded operation are different for different subsystems or their assemblies.

The product usage profile or a mission profile shall include the detailed sequence and magnitude of operational and environmental conditions expected in product use as it is developed based on research and identified customer or user expectations and needs. The profile shall be used in determination of the product reliability goal and for reliability estimation.

Field performance data analysis of a similar fielded product should be done to estimate initial reliability and to set the attainable reliability goal.

Field failure mode reports of a similar product should be used as information on potential failure modes of the newly designed product.

6.2.2 Product definition and preliminary design

Reliability goal inclusion in the product specification ensures that the programme is carried out with every attempt being made to achieve the reliability goal.

Reliability requirements for the key components ensure that those components deemed key for the product operation have realistic reliability expectation such that the product is capable of meeting its allocated reliability goal. Reliability requirements should normally specify maximum tolerable component failure rates as determined for the anticipated operational environment and shall be included in the component specification drawings. When the reliability information is provided for a general (normally 25 °C indoor) environment, it has to be adjusted to the expected operating environment using Arrhenius thermal adjustment or another applicable method.

Initial reliability estimates are made in this phase on the basis of the filed experience of similar products as well as the reliability evaluation of the preliminary design.

The reliability growth plan and model are prepared in this phase to determine what activities are going to be undertaken and what is the necessary number and magnitude of design improvements to achieve the product reliability goal within the given design period.

The reliability growth planning model is based on the idealized reliability growth curve that follows the power law. The assumption that the reliability growth in design does mathematically follow the power law is based on the fact that normally, the failure modes with the highest failure rates are addressed first, and the order of mitigation or reduction in probability of occurrence follows the magnitude of the equivalent failure rate of the failure mode (causes). This means that the failure modes of the highest equivalent failure rates are addressed first (see IEC 61164).

Specific design guidelines for reliability are prepared to ensure that the design practices specific to the product are applied for reliability enhancement.

6.2.3 Project design phase

Reliability assessment, modelling, FMEA/FTA is done to evaluate product reliability at various stages of the design evolution and to identify and mitigate failure modes and their effects, which might pose a potential problem to the operability of the product. Mitigation of those failure modes and their respective causes, or minimization of their effects, contributes to the realization of the product reliability growth.

Failure modes and effects analysis, FMEA (see IEC 60812) of the design needs to be done for each product and needs to provide estimates of all failure modes and their respective causes along with determination of their individual probability of occurrence.

To assess the overall system probability of failure, or reliability, the individual failure modes and causes have to be associated with the hardware and modelled to represent actual system architecture. This can be done by traditional reliability modelling, manually, using commercially available reliability prediction software, or by constructing a fault tree that represents hardware (see IEC 61025 and IEC 60300-3-1), performing this fault tree analysis manually, or using commercially available software such as fault tree analysis software.

The fault tree analysis (FTA), being a top-down engineering analysis, follows all possible fault paths that can be contributors to the failure of the individual assemblies through the low-level gates that represent failure modes of software or of hardware components. Potential causes of individual failure modes are represented normally as basic events with an associated probability of occurrence. The roll-up of the probability values to the top gate provides information on product probability of failure (reliability). The advantage of using the FTA methodology is that both failure mode analysis and reliability modelling are done at the same time, another separate reliability modelling is not necessary, and the design changes are easy to accommodate and to account for.

The magnitude and severities of individual failure modes and causes are estimated to determine priorities for failure mode mitigation or minimization of their probability of occurrence. Absolute priority for mitigation should be given to the failure mode causes that may pose a threat to safety, and that have a reasonable likelihood of occurrence. Failure modes that are critical for product operation and have a high likelihood of occurrence are also very high on the priority list. Change of a component type of reliability quality level is acceptable as a design solution when it has a significant contribution on the assembly or overall product reliability.

Key component selection for reliability ensures that the components that are essential for the product functions do have the required reliability. Their reliability is normally calculated on the basis of the life test information obtained from the components manufacturers and normalized to the usage profile of the product.

Failure mode mitigation is a result of the tight cooperation of design and reliability engineering in finding design solutions for product reliability improvement. It may include design and component changes, component derating consideration, change in layouts, thermal management, and other design solutions available. Mitigation of the failure modes allows product reliability growth.

Reliability testing of components may be done in lieu of analytical determination of their reliability. Here, components may be electronic components, assemblies or subsystems of a product, and the testing may be done for a predetermined time period or for life or for a mission. It is beneficial in cases where their design is not well disclosed (purchased components). The test then is designed in such a way as to ensure reliability allocated to that component for the usage profile defined for the product.

Design reviews, formal and informal, when done with reliability in mind, contribute to the close interaction of design and reliability engineering for the most reliable design (see IEC 61160).

Maintainability assessment assures that the product can be maintained with reasonable ease and cost. It does not contribute directly to the reliability growth, but mitigation of potential failures that may require extensive maintenance does result in reliability growth.

Monitoring of reliability growth consists of plotting the achieved product reliability as assessed during the design period and at times of design improvements (changes), and comparing this growth with the reliability growth model as planned for the product. Any actions necessary for achievement of the planned growth can then be taken on a timely basis.

6.2.4 Tooling, first production runs (preproduction), production phase

Components and product testing for product engineering evaluation, validation of design improvements or validation of replacement components, are some of the last activities, besides the planned reliability growth testing, and prior to production.

Environmental stress screening may be done on preproduction units to evaluate integrity of the manufacturing processes, or can be done on the production units as a means of manufacturing process improvement

Validation testing is done on the preproduction or production units to validate their operability in the extreme operational and environmental conditions specified for the product.

Reliability growth testing is a planned process to identify product failure modes not identified in earlier analyses. As it is a reliability growth method, it is explained separately in 6.3.

Life testing is done on the product, when so required, to determine its life or reliability. More often, it may be done on components that have not been tested by the manufacturer, and that are essential as a potential replacement during the design (product) improvement process.

The reliability report is prepared to capture and document all activities concerning the product reliability analysis, implemented improvements, testing and test results, achieved reliability growth and all lessons learned that may be a useful source of information in the design of another product.

6.2.5 Product fielded phase

Field failure tracking and analysis need to be done with attention to detail so that the information on field failure is captured and can be used for any future product in the first product concept phase, or for improvements of the fielded product whether by product design revisions or by replacements. Reliability growth of the fielded product is addressed in Clause 7.

6.3 Reliability growth activities in the validation test phase

In the validation phase, the product is evaluated as seen from the user's point of view. The test results from this phase may be very difficult to use for the quantitative reliability growth estimation, unless the test conditions from the beginning have been designed to simulate practical use of the product. In the product validation phase for consumer products, the product is often used by the employees of the manufacturer, or by specially selected customers (beta test or test sites). Even when the results of these tests cannot be used for the quantitative reliability growth estimates, the identified failure modes and problems may indirectly, through the action list, enter the qualitative reliability growth process and, in that way, the reliability growth reports.

6.4 Considerations for reliability growth testing

6.4.1 General

It is accepted that, within a practicable and economic test time scale and effort, not all weaknesses can be eliminated. Some weaknesses, both systematic and residual, remain and determine the projected failure intensity or probability of failure. The goal of a reliability growth programme both in product design and test phase is elimination of systematic weaknesses, or reduction of their likelihood of occurrence to an acceptable value to achieve the product reliability goal. The dedicated reliability growth test programme may be carried out for the following two major reasons:

a) To continue reliability growth of the product by subjecting it to the accelerated use environment in an attempt to reveal weaknesses that were unnoticed during design analysis.
b) To demonstrate product reliability when so required by the customer. Here, the classical reliability demonstration by fixed duration testing is substituted by a dedicated reliability growth testing to allow product improvement and at the same time confirm its required reliability. This can take the form of a run-in period or an acceptance testing with a duration fixed by contract.

A typical accumulated testing time for reliability improvement is the reciprocal of the failure intensity (the MTBF) divided by the acceleration factor (see IEC 60300-2 and IEC 60300-3-5), if the reliability has not already been improved by analytical methods or by testing to uncover specific possible failure modes in subsystems or assemblies.

An organized effort that is instrumental in reliability growth test is failure reporting and corrective action system (FRACAS) also spelled out by some as the failure reporting analysis and corrective action system. It is a closed loop system where each of the reported failures is analysed, and when determined to be related to design, a corrective action is instituted for design improvement and failure mitigation. This system allows aggressive reliability growth by forcing closure of the design issues, which occurs only upon validation of the failure mitigation.

6.4.2 Test planning

6.4.2.1 General

Planning of a reliability growth test shall commence at a sufficiently early stage in the programme to allow for the timely delivery of all items and facilities that have to be procured. In preparing a test plan for a reliability growth programme, decisions shall be made concerning:

- the number of items of each type to be tested and status/revision of their design;
- test equipment (both standard and special);
- spare items (modules and components);
- test conditions and environmental facilities;
- expected programme duration in operating time and calendar time;
- manpower for preparation, testing, liaison, repair, analysis, investigation and modification.

6.4.2.2 Number of items to be tested

Increasing the number of items tested simultaneously makes the sample more representative of the total population. Often, the simpler and less complex an item, the lower its cost and the higher its reliability. Therefore, to produce a significant total number of failures in a reasonable time, more items should be tested. This is generally acceptable because of the lower cost and probable smaller physical size per item. It is very important, however, to ensure that testing of multiple units does contribute to the test acceleration. Appearance of some failures is time-dependent (i.e. wear-out, electro-migration), and shortening of the test time by using multiple units may not allow these phenomena to take place. For that reason, it may be prudent to limit the number of test units and to allow enough time, accelerated or otherwise, for these phenomena to occur. A much safer approach is to accelerate the test levels, and to allow the number of failures determine the confidence in test results.

6.4.2.3 Testing by stressing

Because weaknesses are normally revealed only by the appearance of failures, reliability improvement programmes involve both the stimulation of failures and the elimination or reduction of likelihood of appearance of the systematic weaknesses that they expose. However, deliberate stimulation usually applies in laboratory testing rather than in the field.

Selection of appropriate environmental stresses for stimulating failure should be guided by the considerations contained in IEC 60605-2 and IEC 60605-3, but in order to stimulate failures as quickly as possible the test acceleration techniques shall be applied, keeping in mind the design extreme capabilities, which may not be exceeded. If the design specification contains environmental extremes that are equal to, or exceed, environmental ratings of some components or materials, these extremes shall not be applied during the dedicated reliability growth testing, even though those components or materials can withstand them during qualification testing that is of a limited duration. As an example, a product containing electrolytic capacitors rated to 85 °C may pass the exposure to 85 °C of the high-temperature qualification test, but the same capacitors would fail during extended exposure to the same temperature during a reliability growth test sequence. Operational stresses shall also be accelerated but shall not exceed the maximum rating of the components in the tested product.

Environmental stresses and operational patterns shall be related to the conditions of use of an item but may be designed to give increased stimulation of latent weaknesses. Care should be taken not to introduce failure mechanisms atypical of normal use, which might render mathematical modelling unrealistic. Separate engineering evaluation or qualification tests in extreme environments, if carried out, may provide additional failure data. The type and severity of stimulation used may vary according to the level of assembly.

To ensure that all failures are detected, a comprehensive and frequent schedule of performance tests against the test specification shall be carried out during the test. Where imbedded software is involved in the item, this testing schedule should embrace all expected modes of operation and their likely combinations.

6.4.2.4 Programme duration

The time required to achieve a given target reliability can be predicted only on the basis of past experience (private or published) with the aid of reliability growth modelling. Mathematical models provide a means of predicting the number of relevant failures based on assumed model parameters estimated from previous programmes. This figure is then adjusted to allow for additional failures, i.e. non-relevant failures and repetitions of systematic failures from weaknesses still present. The average calendar time to repair and to make modifications is also estimated, together with a contingency for loss of facilities, sickness, etc.

The calendar time for the total programme shall be the sum of

– the total operating time required, converted to calendar time according to the maximum number of hours possible per week (or month);
– the total downtime to repair all expected failures;
– the total downtime for modifications to correct all expected systematic weaknesses.

6.4.2.5 Planned growth and growth monitoring

The user shall specify a target reliability measure for the equipment being tested.

In order to be able to assess progress in reliability growth towards this level during the programme, a planned growth curve may be prepared. This will show the reliability to be expected at specified points in the programme, in terms of calendar or test times. If the programme is conducted in distinct time phases, then these points may coincide with the ends of phases.

The planned overall growth pattern or “idealized growth curve” should normally be constructed from an accepted mathematical model (see IEC 61164) whose parameters reflect a realistic rate of growth based on experience with the effect of past activities. If there are distinct phases, an individual target within each phase shall be set. At the specified points in the programme, the actual growth as estimated by modelling should be compared with the planned growth (growth monitoring).

6.4.3 Special considerations for non-repaired or one-shot (expendable) items and components

The principles which apply to a reliability growth programme for repairable items also apply in general to a programme specially intended to improve the reliability of non-repaired or one-shot items or components. There are, however, some differences from an equipment programme. In this case, the most common reliability measures are failure rate and MTTF.

Each sample of identical type items undergoing testing should be as large as possible. An item that fails need not be replaced, provided the sample is not substantially reduced in size. In order to expose any further undiscovered inherent weaknesses, testing should continue in parallel with any systematic failure analysis. Systematic failures should normally be followed by corrective modification of the item, after which the entire sample under test is promptly upgraded to the modified version. Testing should recommence to verify the effectiveness of this and other modifications and to continue to reveal further unknown weaknesses. In some cases it may be decided to continue a test even though a test with a new revision is started, just to find failures that do not occur until after a longer operating time (i.e. wear-out).

Where the wear-out of the item is significant, improvement consists in extending this lifetime (Weibull location parameter) and in reducing the variation of the lifetime (Weibull shape parameter). Those activities require other methods such as Weibull analysis (see IEC 60605-4).

6.4.4 Classification of failures

Classes of failure, which do not result from those basic causes in design or construction, as described in Clause 4, are non-relevant to corrective modification and to growth modelling and assessment. The first stage in classification is to identify and exclude failures that are non-relevant and the second stage is to subdivide the relevant failures into systematic and residual failures.

Classification requires engineering judgement, based on as much information as is obtainable from investigations. Classification attempts to trace backwards the conceptual sequence described in 4.2, i.e. from failure to weakness and to the nature of the original cause.

6.4.5 Classes of non-relevant failures

Non-relevant failures, in general, are covered by 7.2.1 of IEC 60300-3-5. Depending upon the special requirements of particular programmes (as defined in the appropriate specification or plan), some or all of the types of failure listed below may be classified as not requiring corrective modification and also as being non-relevant to reliability growth assessment (see 6.4.9).

If failures of any of the following types carry wider implications of unreliability, for example, in interfaces, associated equipment or test gear, they may be relevant to corrective modification in these areas even if they are non-relevant to the main item in the programme.

a) **Secondary failures**

   NOTE See 7.2.1.1 of IEC 60300-3-5.

   If considered to be systematic, these failures are relevant.

b) **Misuse failures**

   NOTE See 7.2.1.2 of IEC 60300-3-5.

   If considered to be systematic, then these failures are relevant.

c) **Failure in the process of correction, or already eliminated by design correction**

   NOTE See 7.2.1.3 of IEC 60300-3-5.

   When mathematical models are used for reliability growth assessment, individual requirements may or may not exclude these failures.

d) **Identical intermittent failures**

   After the first appearance of any one type, such failures may be non-relevant.

   The underlying weakness is very likely to be systematic and hence relevant.

e) **Failure needing operator adjustment or maintenance (normal operator use only)**

   Failures that can be corrected by these means may be non-relevant.

   If considered to be systematic, then these failures are relevant.

f) Components failing to meet specification tests but satisfactory in their particular function

If the overall performance of a piece of equipment is unimpaired, such failures, which may be detected during investigation, may be non-relevant.

g) Failures that occurred after acceptable lifetime

Failures of items subject to wear-out, which fail after the specified minimum lifetime, may be non-relevant.

h) Failures during reliability screening

These failures shall be non-relevant to reliability growth assessment. However, failures revealing new systematic weaknesses in reliability screening always require investigation and possible corrective modification.

6.4.6 Classes of relevant failures

Relevant failures should be classified as either systematic or residual for two reasons:

- to decide whether corrective modification is required;
- for some methods of reliability growth modelling, to provide separate failure category inputs.

The following ground rules have been found to be useful in classifying failures.

a) Systematic failures

Systematic failures are those that exhibit, after a physical, circumstantial or design analysis, a condition or pattern, which may be expected to cause recurrence. This may be confirmed by actual recurrences after a sufficiently long test time. For example, a component, which is found to be mildly over-stressed due to a design error, might show recurrent failures over a sufficiently long period.

b) Residual failures

Residual failure are those that show no pattern of failure recurrence and whose causes do not suggest that recurrence is likely, for example, an apparent rogue component or chance error of workmanship.

Classifications shall be constantly reviewed as later events may provide new evidence to support reclassification, most often towards a systematic failure category B (see Figure 8).

6.4.7 Categories of relevant failures that occur in test

Systematic failures should be classified as category A or B as explained below:

a) those not to be followed by corrective modifications because the expected results would not justify the cost, time or technical difficulty;

b) those which are followed by corrective modification aimed at preventing their recurrence.

6.4.8 Process of reliability improvement in reliability growth tests

Figure 8 shows the sequence of failure diagnosis, repair or replacement, classification and (where applicable) further investigation and corrective modification. The same general process shall apply where the source of information is an informal programme or an activity having a different primary objective.

In order to minimize interruptions, the testing should be suspended at the time of a failure only long enough to permit diagnosis and repair, withdrawal or replacement. As far as possible, investigation of systematic failures and design of modifications should continue in parallel with testing, with the risk, of course, of repetitions of the same type of failure while the weakness still persists.

Systematic failures in category B should always be followed by corrective modification. When the modification has been devised it may be incorporated at the earliest convenient stopping-point (i.e. at the occurrence of another failure or other interruption). However, more efficient operation may be achieved if the programme is divided into distinct time phases and some (especially large-scale) modifications delayed until the end of each phase. Figure 8 shows an example of this.

Modules or other replacement units may be exchanged for spares to restore operation after a failure. This allows the modification to be incorporated into the spare unit independently, with further down-time saving when it is reintroduced later. It is therefore an advantage to have a set of such spare units, but unless they include all previous modifications they should be used only temporarily.

The effectiveness of a modification is not known until after a period of testing that is several times longer than the period to first failure due to a particular type of weakness. This shows not only whether the effects of a particular weakness have been successfully reduced or eliminated, but also whether alternative systematic weaknesses have been introduced. Any errors in workmanship or in new components, bringing new residual weaknesses, shall also require a period of operation (similar to that for reliability screening) in order to expose them. As a statistical tool, comparison testing can be used (see IEC 60300-3-5).

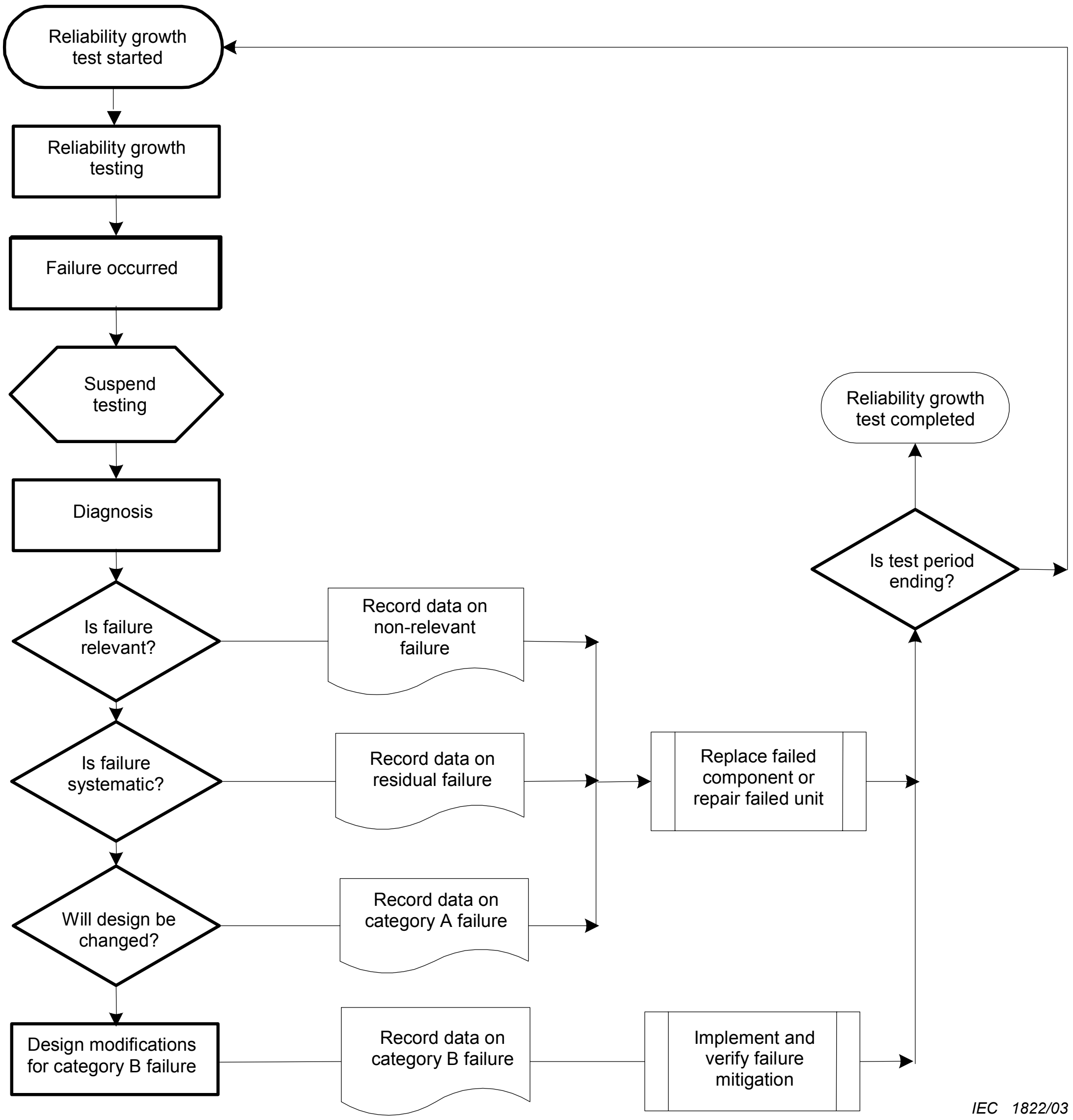


Figure 8 – Process of reliability growth in testing

6.4.9 Mathematical modelling of test reliability growth

This clause describes the modelling applicable where reliability is measured by failure intensity or by MTBF. For other measures of reliability, for example, failure rate, MTTF or success ratio, alternative types of model should be used. Reliability growth modelling enables quantitative estimates to be made of the achieved and future reliability measures at the end of a reliability growth programme or at intermediate points, expressed in the following forms:

– the instantaneous failure intensity or MTBF at a given point in the programme;
– the extrapolated failure intensity or MTBF at some future point in the programme;
– the projected failure intensity or MTBF beyond the time when delayed modifications are incorporated or improvement ceases.

The instantaneous or extrapolated failure intensities are of greatest use while the programme is in progress and the projected measure is of the most value as a final estimate at the end of a phase or the end of the programme.

In addition, the following ratios may be estimated:

– the measures listed above, relative to the current measure at the start of the programme;
– the number of systematic weaknesses revealed, relative to the total inherent number as estimated by modelling;
– the number of systematic weaknesses acted upon by modification, relative to the total inherent number.

The length of the early failure period may be estimated directly from the failure data, by visual examination of the failure/time characteristic or by other means. Both failures and times within this period shall be excluded from data used in reliability growth calculations.

There are several mathematical models currently in use dependent on user preference and the type and duration of the reliability growth programme. Some of those are the Duane model, the AMSAA/Crow model, and the IBM/Rosner model of a fixed number of defects.

6.4.10 Nature and objectives of modelling

Reliability growth models use mathematical functions which, when their variables or parameters have optimum values for a particular data set, closely reproduce the characteristics of that data set. Such functions and characteristics are best expressed in the same form as the original data set, which consists of accumulated numbers of relevant failures and corresponding accumulated relevant test times at each failure, as in Figure 9. The functions of the models may be either in continuous or discrete form. A discrete model represents failures more realistically as distinct steps, but often requires more stages in evaluation than a continuous model.

Choice of the model to be used involves a compromise between simplicity and evaluation and realism. Most models have not more than two parameters because a greater number complicates evaluation. Equations are solved in order to obtain maximum likelihood or least squares estimates of the parameters. By substitution of these values in the model function, the growth achievement is then derived, in the forms listed at the beginning of 6.4.9.

Two important requirements for modelling are that

– there should be adequate data,
– the testing environment should follow a consistent pattern.

The models should not be regarded as infallible, nor should they be applied without discretion, but used as statistical tools to aid engineering judgement.

6.4.11 Concepts of reliability measures in reliability growth testing as used in modelling

6.4.11.1 Instantaneous failure intensity

As already shown by curve (3) of Figure 4, the characteristic of total relevant failures against test time is generally of the form shown by the solid curve of Figure 9.

At any point in time, the instantaneous failure intensity is the slope of the tangent to the curve at that point. Figure 9 shows tangents drawn at the origin and at an intermediate point (t_1, n_1) of a reliability improvement programme, whose slopes represent instantaneous failure intensities of the item (or population of items). These slopes can be estimated after a curve-fitting process employing a mathematical model.

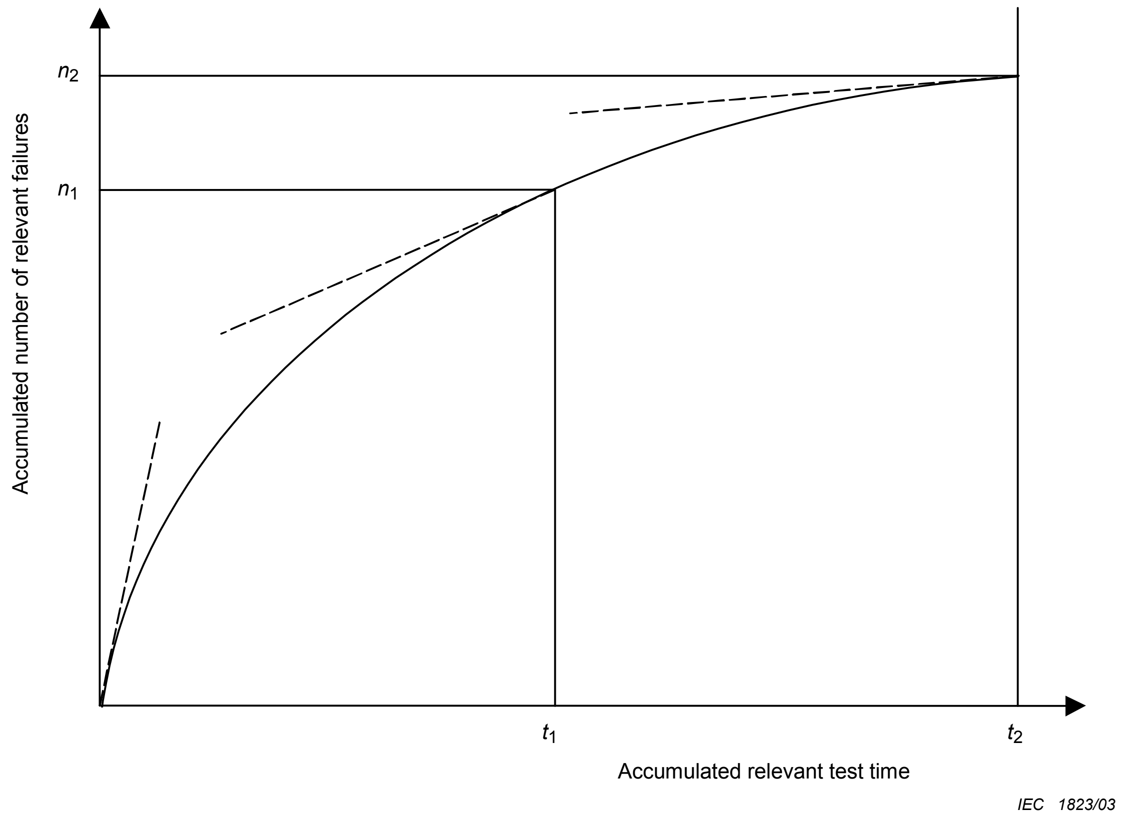
However, if modifications to improve the reliability have been made in the later stages of the total testing period, the model may not have had a long enough period to reflect the resulting growth. Consequently, the true instantaneous failure intensity will be lower than that estimated. This is a special problem if most or all of the modifications have been delayed until the end of testing (or a particular phase of testing). This method of assessing reliability cannot then be used and only the projected failure intensity can be estimated as described in 6.4.11.3.

6.4.11.2 Extrapolated failure intensity

Figure 9 shows the tangent drawn at point (t_2, n_2) whose slope represents the extrapolated failure intensity at that point, as estimated by extrapolation from point (t_1, n_1). It is assumed that the same model and parameters which applied to the failure data accumulated up to point (t_1, n_1) shall continue to apply up to point (t_2, n_2) and that the testing conditions and prompt modification procedures are unchanged throughout the programme.

Thus, the extrapolated failure intensity is a forward estimate or prediction of the level expected at some future stage or at the end of the programme. However, it should be remembered that changing the test conditions or the modification procedure may invalidate the extrapolation.

The curve shown in Figure 9 is an example only and does not represent what might occur in a real test, as it might be possible that the failure occurrence becomes more, rather than less, frequent. A similar curve representing real test data may be made for individual tests.



Key

Slope of tangents at origin and at (t_1, n_1) = instantaneous failure intensity

Slope of tangent at (t_2, n_2) = extrapolated failure intensity

Figure 9 – Characteristic curve showing instantaneous and extrapolated failure intensities

6.4.11.3 Projected failure intensity

The projected failure intensity is that which is expected to apply to an operation subsequent to a modification programme. A programme consisting of several modifications made simultaneously causes a jump in reliability as shown in Figure 11, instead of continuous growth. If projected failure intensity is estimated at the end of the reliability growth programme, then it is relevant to operation in the field, if the same environment can be assumed. Projection is more indirect and requires more engineering judgement than estimation of instantaneous or extrapolated failure intensity.

At the time of estimation there is no evidence, resulting from tests, that all the modifications have improved the reliability to the extent intended and without introducing new types of weaknesses. It is found that few modifications are completely effective, and may in some cases introduce new failures. An “improvement efficiency factor” is expressed as the expected fractional reduction in the failure intensity. This factor may be assigned by engineering judgement for each modification or as an overall average (typically 0,7).

The projection technique assumes that each identifiable type of systematic weakness has its own constant failure intensity after the early failure period, which could be demonstrated if enough recurrent failures of this type were allowed. Of course, with prompt and successful modifications, only the time to first failure of each type is available for the purpose of estimating this failure intensity.

The following steps are performed:

a) Using the set of times to first failure of all systematic types, a model estimates the failure intensity of each known type of systematic failure.

b) An improvement efficiency factor is applied.

c) The total failure intensity due to all the systematic weaknesses not yet detected is estimated by the model.

d) Because residual failure intensity is assumed constant, it is easily estimated directly by dividing the total number of residual failures by the accumulated relevant test time.

e) The projected total failure intensity is estimated as the sum of the individual failure intensities due to the following weaknesses:

– known systematic weaknesses, on which corrective modifications may or may not have been attempted;

– undetected systematic weaknesses, predicted by the model, but not yet observed;

– residual weaknesses.

Figure 10 illustrates these concepts.

These principles apply both to hardware and software, except that for software the residual failure intensity is always nil.

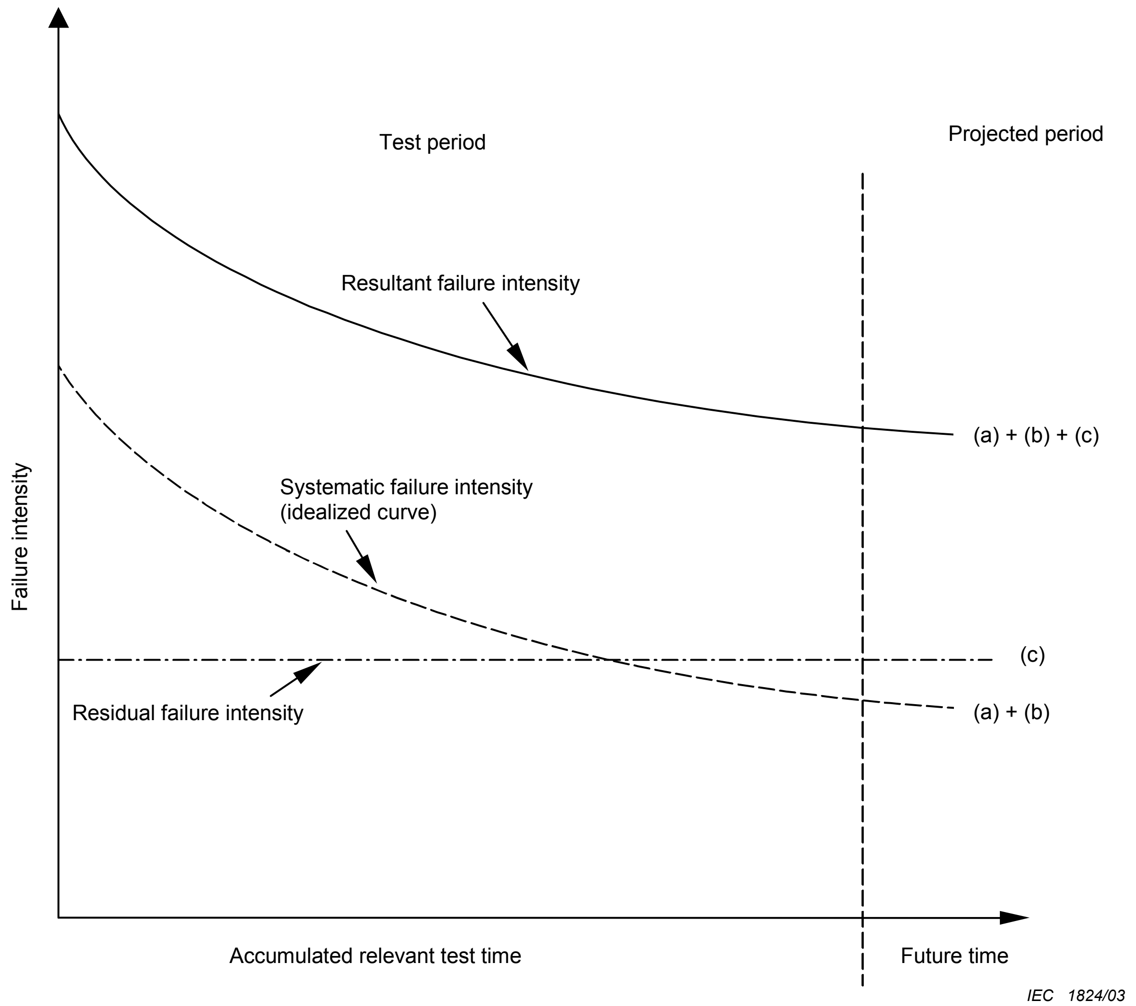


Figure 10 – Projected failure intensity estimated by modelling

6.4.11.4 Other estimates

The ratio of failure intensities as a measure of growth during a phase or throughout the programme can be measured by estimating the projected intensity and dividing it by the instantaneous value at the start of the programme. For models, which estimate the total number of types of inherent systematic weakness (including those undetected) the fraction detected and acted upon is easily derived for information. Further, the fraction that has resulted in modification is derived from the known number of category B failures. The degree of success of all the modifications and the accuracy of the arbitrary improvement efficiency factors can be assessed only from further testing or field experience.

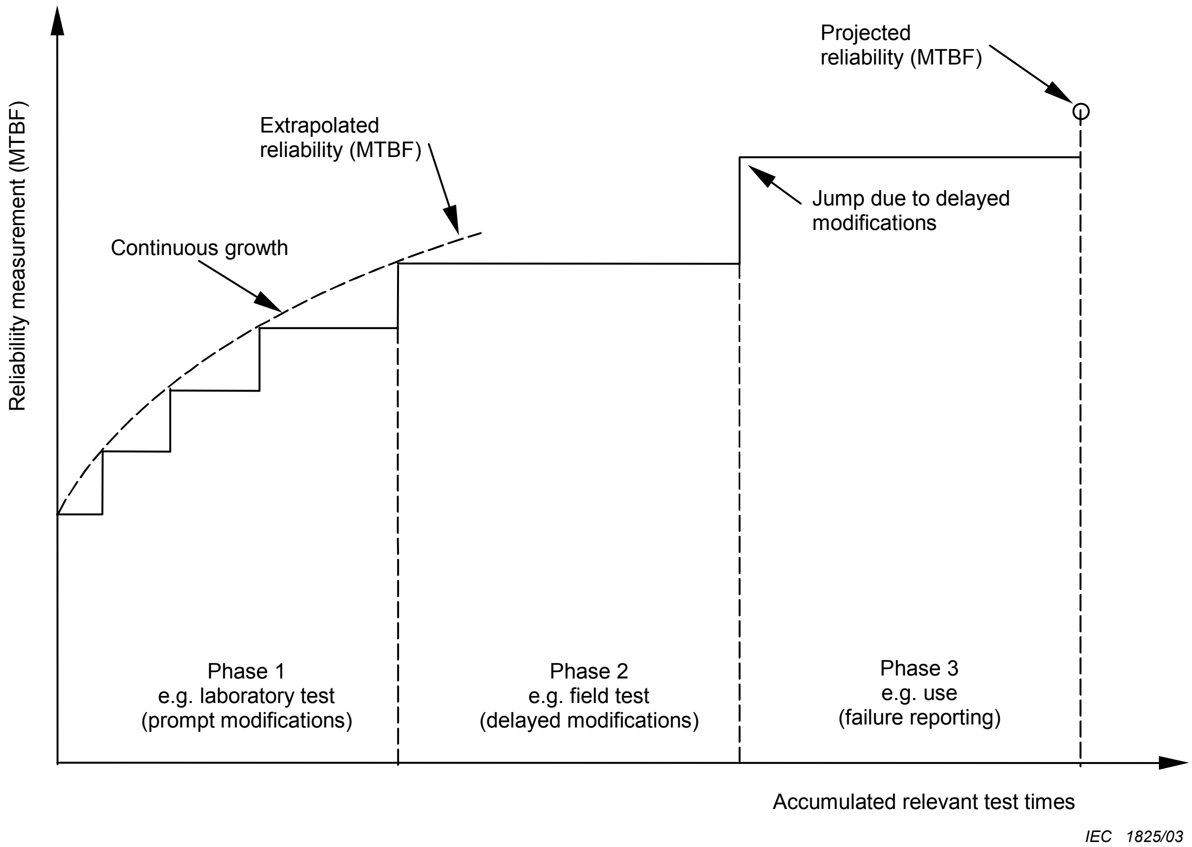


Figure 11 – Examples of growth curves and "jumps"

6.4.12 Reporting on reliability growth testing and documentation

The reporting and documentation of the reliability growth shall be continuous in order to monitor the process and, if needed, add resources. Therefore, the documentation should be continuously updated, for example at each project meeting (for a guide on documentation, see IEC 60300-3-5). A formal report should be issued at each milestone for the project and at each design release and prototype build.

The report should describe the growth and should list the instantaneous failure intensity, the extrapolated failure intensity, as well as the projected failure intensity, with the planned activities. Furthermore, the status of the action list through time should be shown for each class of severity as well as for the different status of the problems. The report should conclude with an evaluation of the reliability and risks for the product, the qualitative confidence of these conclusions, and it should point out if a gap exists between the reliability target for the product and the projected failure intensity. The report should further compute the coefficient(s) of improvement achieved for the statistical reliability growth models used. Together with a list of the actually performed analysis, test and improvement activities this (these) coefficient(s) is (are) used for planning and projection of reliability measures for new projects in the same organization.

Documentation for a reliability growth programme shall take the following form.

a) A test plan usually prepared by the manufacturer and approved by the customer, detailing all the tasks comprising the reliability growth programme, the environment and the test facilities. These tasks shall include analysis activities, preparation and setting up, testing, monitoring, documentation and the procedure to be adopted after failure. A planned growth curve may be required.

b) A test specification, detailing regular monitoring of the functional performance of an item.

c) A daily log for recording test results, failures and other significant events.

d) A failure report for recording and notifying each failure, relevant or non-relevant. This should preferably be on a standard form used by the manufacturer for all sources of failure data and designed for easy entry of essential data into a databank.

e) A failure analysis report giving results of investigations and analyses and, where appropriate, actions arising from failures.

f) Interim reports at specified intervals to include, if required, plots comparing actual growth with planned growth (see Figure 8).

g) A final report describing the programme and presenting all essential results, actions and conclusions including reliability estimates by mathematical modelling.

Both d) and e) shall have a unique numbering system enabling each failure and its analysis to be related to each other and to the project or item concerned. Subsequent reports that update the situation shall reference all relevant previous reports.

Detailed information about reports on general reliability testing is given in IEC 60300-3-5.

7 Reliability growth in the field

It is possible to continue reliability growth of the fielded product. Review of the field data contained in a well-organized filed failure tracking system can reveal design-related problems not uncovered in analysis and test. Duplication of the failure and a thorough analysis may lead to a design flaw that can be a subject for redesign and improvement. This design improvement can be included into the further production runs. Careful monitoring of the field data regarding those particular failures and the lack of their re-appearance then leads to a conclusion of a successful fix resultant to reliability improvement of the product.

Monitoring of the field reliability growth, even though not impossible, may be difficult as there are other changes in the product, besides design improvement. Production variations of the product itself along with the variations of components reliability dependent on production variations of their respective manufacturers as well as the differences between multiple vendors of the same component types are at times impossible to control.

For a better field-data quality it is essential to organize data collection in such a way that failure descriptions are uniform (standardized) and that as much as possible detail on the failure is recorded.

Even if not quantitatively monitored, reliability growth in the field is noted by no repetitiveness in systematic failures and reduction in service demands.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60300-1	- [1]	Dependability management Part 1: Dependability management systems	EN 60300-1	2003 [2]
IEC 60300-2	- [1]	Part 2: Dependability programme elements and tasks	EN 60300-2	1996 [2]
IEC 60300-3-1	- [1]	Part 3-1: Application guide - Analysis techniques for dependability - Guide on methodology	-	-
IEC 60300-3-5	2001	Part 3-5: Application guide - Reliability test conditions and statistical test principles	-	-
IEC 60605-2	- [1]	Equipment reliability testing - Part 2: Design of test cycles	-	-
IEC 60605-3	Series	Equipment reliability testing - Part 3: Preferred test conditions	-	-
IEC 60605-4	- [1]	Part 4: Statistical procedures for exponential distribution - Point estimates, confidence intervals, prediction intervals and tolerance intervals	-	-
IEC 60812	- [1]	Analysis techniques for system reliability - Procedure for failure mode and effects analysis (FMEA)	HD 485 S1	1987 [2]
IEC 61025	- [1]	Fault tree analysis (FTA)	HD 617 S1	1992 [2]
IEC 61160	- [1]	Formal design review	-	-

[1] Undated reference.

[2] Valid edition at date of issue.

Publication	Year	Title	EN/HD	Year
IEC 61164	– [1)]	Reliability growth - Statistical test and estimation methods	-	-

Bibliography

IEC 60050(191):1990, *International Electrotechnical Vocabulary (IEV) – Chapter 191: Dependability and quality of service*

IEC 60319, *Presentation and specification of reliability data for electronic components*

IEC 61882, *Hazard and operability studies (HAZOP studies) – Application guide*

IEC 61703, *Mathematical expressions for reliability, availability, maintainability and maintenance support terms*

IEC 61710, *Power law model – Goodness of fit tests and estimation methods*

ISO 9000, *Quality management systems – Fundamentals and vocabulary*

ISO 9001, *Quality management systems – Requirements*

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