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Australian Standard®

Equipment reliability—Reliability assessment methods

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Australian Standard®

Equipment reliability—Reliability assessment methods

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PREFACE

This Standard was prepared by the Standards Australia Committee QR-005, Dependability.

The objective of this Standard is to describe methods for early reliability assessment of items based on field data and test data for components and modules and applicable to mission, safety and business critical high integrity and complex items. It includes guidance on related activities, management of the reliability assessment process, and reliability programme planning and monitoring.

This Standard is identical with, and has been reproduced from IEC 62308 Ed.1.0 (2006), *Equipment reliability—Reliability assessment methods*, which is part of a suite of Standards developed by the IEC Technical Committee IEC/TC 56, Dependability, and is suitable for use in conjunction with the AS IEC 60300 series of dependability management Standards.

As this Standard is reproduced from an International Standard, the following applies:

(a) Its number does not appear on each page of text and its identity is shown only on the cover and title page.

(b) In the source text ‘this International Standard’ should read ‘this Australian Standard’.

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The terms ‘normative’ and ‘informative’ are used to define the application of the annex to which they apply. A normative annex is an integral part of a standard, whereas an informative annex is only for information and guidance.

CONTENTS

INTRODUCTION

This International Standard describes procedures that are intended for use in assessing the reliability of items based on data from: the market of similar items; and field data and test data from suppliers of components and modules. The results of such assessments are intended for use as inputs to early equipment design decisions such as system architecture selection as well as business decisions such as estimating the cost of warranties or maintenance cost guarantees. Furthermore the results can be used as the initial estimate for input to safety analysis, for example FTA analysis. Modern electronic components and items are so reliable that estimating or verifying their reliability by testing is very difficult, therefore data from the field for previous similar items are often the only way to get an initial estimate of the reliability. Component manufacturers have used this method for years under the name of the "similarity principle". By emphasising the use of data from previously marketed similar products, and requiring similarity to be documented, the method is a modern alternative to the classical but now obsolete handbook prediction.

Reliability assessment results should be viewed as an early estimate of the probability that the product reliability targets and goals can be satisfied using the chosen architecture, modules, components and maintenance policy. As such, they may be used, for example, to authorize advancement to the next step in product development, or to authorize progress payments, or to proceed with delivery and acceptance of products. Reliability assessment results should never be used to support a claim that the reliability targets, goals, or expectations have been satisfied. The only certain measure of reliability requirement having been met is from service/field performance. This standard describes the uses for reliability assessment results as well as providing a list of IEC standards that require such results as input.

The approach to reliability assessment in this International Standard

- encourages the equipment manufacturer to consider all relevant information regarding equipment reliability which may include the effects of design and manufacturing processes as well as component selection issues. This is in contrast to more traditional methods that focus on component reliability as the most significant contributor to the equipment reliability;
- encourages the equipment manufacturer to define and use the processes that are most effective for the manufacturer's own equipment;
- describes a continuous procedure in which a reliability assessment can be updated as more information becomes available during the life cycle of the equipment. This information may be used to improve both the reliability of the equipment and the effectiveness of the assessment process.

This International Standard describes the application of three approaches to reliability assessment, namely: similarity analysis, durability analysis, and handbook predictions. This standard does not, however, provide information on assessing the reliability of software systems but can be used for assessing the reliability of hardware systems containing embedded software.

STANDARDS AUSTRALIA

Australian Standard

Equipment reliability—Reliability assessment methods

1 Scope

This International Standard describes early reliability assessment methods for items based on field data and test data for components and modules. It is applicable to mission, safety and business critical, high integrity and complex items. It contains information on why early reliability estimates are required and how and where the assessment would be used. Finally, it details methods for reliability assessment and the data required to support the assessment. To estimate durability (life time or wear-out), the physics-of-failure method is used.

Three types of assessment are discussed in detail:

– the similarity approach;
– models for durability analysis;
– handbook methods.

Clause 6 provides an introduction to reliability assessment and Clause 7 the management of the process. Clause 8 describes the data needs, sources and types for assessments and Clause 9 provides details of the assessment methods.

Annexes A and B provide additional information to aid understanding of the similarity analysis and durability analysis.

This standard is applicable to making reliability estimates for specifications, design, design modification and support engineering.

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.

References to international standards that are struck through in this clause are replaced by references to Australian or Australian/New Zealand Standards that are listed immediately thereafter and identified by shading. Any Australian or Australian/New Zealand Standard that is identical to the International Standard it replaces is identified as such.

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

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

AS IEC 60300.1, *Dependability management— Dependability management systems*

~~IEC 60300-3-1:2003, *Dependability management – Part 3-1: Application guide – Analysis techniques for dependability – Guide on methodology*~~

AS IEC 60300.3.1, Dependability management—Application guide—Analysis techniques for dependability—Guide on methodology

IEC 60300-3-2, *Dependability management – Part 3-2: Application guide – Collection of dependability data from the field*

~~IEC 60300-3-3, *Dependability management – Part 3-3: Application guide – Life cycle costing*~~

AS IEC 60300.3.3, *Dependability management—Application guide—Life cycle costing*

IEC 60300-3-4:1996, *Dependability management – Part 3: Application guide – Section 4: Guide to the specification of dependability requirements*

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

~~IEC 60300-3-9, *Dependability management – Part 3: Application guide – Section 9: Risk analysis of technological systems*~~

AS/NZS 3931, *Risk analysis of technological systems—Application guide*

~~IEC 60300-3-11, *Dependability management – Part 3-11: Application guide – Reliability centred maintenance*~~

AS IEC 60300.3.11, *Dependability management—Application guide—Reliability centred maintenance*

~~IEC 60300-3-12, *Dependability management – Part 3-12: Application guide – Integrated logistic support*~~

AS IEC 60300.3.12, *Dependability management—Application guide—Integrated logistic support*

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

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

~~IEC 61025, *Fault tree analysis (FTA)*~~

AS IEC 61025, *Fault tree analysis (FTA)*

~~IEC 61078, *Analysis techniques for dependability – Reliability block diagram and boolean methods*~~

AS IEC 61078, *Analysis techniques for dependability—Reliability block diagram and Boolean methods*

~~IEC 61160, *Design review*~~

AS IEC 61160, Design review

~~IEC 61165, *Application of Markov techniques*~~

AS IEC 61165, *Application of Markov techniques*

IEC 61508 (all parts), *Functional safety of electrical/electronic/programmable electronic safety-related systems*

IEC 61649, *Goodness-of-fit tests, confidence intervals and lower confidence limits for Weibull distributed data*

IEC 61709, *Electronic components – Reliability – Reference conditions for failure rates and stress models for conversion*

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

IEC 61713, *Software dependability through the software life-cycle processes – Application guide*

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

IEC 62380, *Reliability data handbook – Universal model for reliability prediction of electronics components, PCBs and equipment*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-191, together with the following, apply.

3.1
durability analysis
analysis of the equipment's responses to the stresses imposed by operational use, maintenance, shipping, storage and other activities throughout its specified life-cycle in order to estimate its predicted reliability and expected life

3.2
life-cycle
time interval between a product's conception and its disposal

3.3
similarity analysis
structured comparison of the elements of the equipment being assessed with those of predecessor equipment for which in-service reliability data are available

4 Abbreviations

ASIC	Application specific integrated circuit
BITE	Built in test equipment
COTS	Commercial off the shelf
FEA	Finite element analysis
FFOP	Failure free operating period
FITS	Failure per thousand million hours
FMEA	Failure mode and effects analysis
FMECA	Failure mode, effects and criticality analysis
FRACAS	Failure reporting, analysis and corrective action system
FTA	Fault tree analysis
HALT	Highly accelerated life test
IC	Integrated circuit
LCC	Life cycle costs
LRU	Line replaceable unit
MCTF	Mean cycles to failure
MTBF	Mean time between failures

MTBUR	Mean time between unit repair
MTTF	Mean time to failure
MTTR	Mean time to restoration/recovery/repair
MTTSC	Mean time to service call
MTTSI	Mean time to service interruption
MTTWC	Mean time to warranty claim
RBD	Reliability block diagram
RCM	Reliability centred maintenance
RET	Reliability enhancement test
SRU	Shop replaceable unit

5 Symbols

λ	Constant failure rate of the exponential distribution
t	Time period of interest
$f(t)$	Probability density function
$F(t)$	Cumulative distribution function
$R(t)$	Reliability function
T^*	Accumulated exposure time

6 Introduction to reliability assessment

6.1 Introductory remarks

The reliability of an item will often have to be assessed for a range of reasons including the following:

a) setting targets and specifications;

b) comparing options;

c) identifying and prioritising problems;

d) indicating fitness for purpose;

e) optimizing support (e.g. spares);

f) to give input to other analysis (e.g. safety analysis);

g) to prioritise areas for improvement with the greatest cost-effectiveness improvement potential.

This reliability may be quoted in a number of ways, including for example

– accumulated percentage of failures;
– call rate;
– probability of survival;
– failure intensity;
– instantaneous failure rate;
– MTTF;
– MTBF.

The procedure outlined in this standard is aimed at providing reliability analysts, project managers, risk management engineers, designers, safety and reliability engineers, and logistic support engineers with an assessment method for an early estimate of an item's instantaneous failure rate. The process for estimating life for items with a wear-out failure characteristic is also included.

6.2 Description of reliability assessment

6.2.1 General information

Reliability is not an attribute that can be assigned or measured for a single item. It is a stochastic or probabilistic parameter and therefore it cannot be measured exactly and repeatedly. It therefore has to be estimated from information on the amount of usage (e.g. running hours, cycles of operation, etc.) and the number of failures observed. It should be presented in the form of a confidence statement such as "80 % confidence that the true probability of successfully completing the mission lies between X and Y" or "period of time of interest without failure is between 0,963 and 0,995". An explanation of confidence and confidence intervals can be found in IEC 61649.

The classical definition of reliability is the probability of providing a specified performance level for a specified duration in a specified environment. Although such a probability is a useful measure for mission-oriented, low-volume products such as spacecraft, it is rarely a suitable measure for most high-volume products for which reliability relates more to product population than the performance of a single system or a mission. Specifying a single characteristic such as mean time to failure (MTTF) is not sufficient for a product that exhibits a time-dependent failure rate (i.e. non-constant failure rate).

6.2.2 Constant failure rate reliability measures

The general expression for reliability, $R(t)$, is given by

$$R(t) = \exp\left(- \int_{t}^{\infty} \lambda(t) dt \right) \quad (1)$$

where $\lambda(t)$ is the instantaneous failure rate.

Another very useful (general) expression is

$$f(t) = -\frac{dR(t)}{dt} = \frac{dF(t)}{dt} \quad (2)$$

where $f(t)$ is the probability density function of times to failure. In terms of these quantities the instantaneous failure rate is given by

$$\lambda(t) = \frac{f(t)}{R(t)} \quad (3)$$

Yet another fundamental general expression is that for MTTF. This quantity is given by

$$\text{MTTF} = \int_{0}^{\infty} R(t) dt \quad (4)$$

Now when $\lambda(t)$ is constant with time, it should simply be written as λ. Under these circumstances, times to failure follow an exponential distribution and the following relationships hold:

$$R(t) = \exp(-\lambda t) \tag{5}$$

$$f(t) = \lambda \exp(-\lambda t) \tag{6}$$

$$\lambda(t) = \lambda \tag{7}$$

$$\text{MTTF} = \frac{1}{\lambda} \text{ often denoted by the symbol } \theta \tag{8}$$

This only holds when λ is constant.

Another useful but problematic quantity is the total accumulated number of product-hours, sometimes denoted by T^*. Under the assumption of constant failure rate there is no difference from a statistical point of view between accumulating 1 000 000 h by one product, or 1 h by 1 000 000 products. In either case a point estimate of the population failure rate if there is one failure would be 10^{-6} failures per product-hour.

The parameter λ being independent of time is referred to as the constant failure rate. A constant failure rate has many useful properties, one of which is that the mean value of the distribution of the product's time to failure is $1/\lambda$. For non-repaired items (components), this mean value represents the statistically expected average length of time until product failure, commonly called the mean life or MTTF. This means that 63 % of the items can be expected to fail from time 0 until MTTF and 37 % after the MTTF. Another useful property of the constant failure rate is that it can be estimated from a population as the fractional decrease in the number of surviving items per unit time. However, it should be noted that the exponential distribution is the only distribution for which the failure rate is a constant and that the mean life is not $1/\lambda(t)$ when the failure rate is not constant.

For repaired items, MTTF is sometimes misunderstood to be the life of the product rather than the reciprocal of the constant failure rate. If a product has an MTTF of 1 000 000 h, it does not mean that the product will last that long (longer than the average human lifetime). Rather, it means that, on average, one of the products will fail for every 1 000 000 product-hours of operation, i.e. if there are 1 000 000 products in the field on average, one of them will fail in 1 h on average. In this case, if product failures are truly exponentially distributed, then on average 63 % of the products will have failed after 1 000 000 h of operation. Products with truly exponentially distributed failures over their entire lifetime almost never occur in practice, but a constant failure rate and MTTF may in some cases be a good approximation to product failure behaviour.

Table 1 – Example of constant rate reliability measures

Constant rate measure	Mean life equivalent	Definition	Use
Constant failure rate using time	MTTF (mean time to failure)	Total failures divided by total population operating time	Standard measure for reliability predictions when time is the relevant parameter
Constant failure rate using cycles or distance instead of time	Mean cycles/ km MCTF	Total failures divided by total population number of product cycles or distance, e.g. kilometres	Standard measure for reliability predictions when usage is more relevant than time. These measures are sometimes converted to time-based measures by specifying an operating profile or duty ratio
Constant restoration/repair rate	MTTR (mean time to restoration/ repair)	Total restorations/repairs divided by total population operating time	Useful for sizing a repair depot or manufacturing repair line
Constant replacement rate	MTTR (mean time to replacement)	Total replacements divided by total population operating time	Used as surrogate for constant failure rate when no failure analysis is available; useful for warranty analysis
Constant service or customer call rate	MTTSC (mean time to service call)	Total service/customer calls divided by total population operating time	Customer perception of constant failure rate; useful for sizing support needs
Constant warranty claim rate	MTTWC (mean time to warranty claim)	Total warranty claims divided by warranted population operating time	Useful for pricing warranties and setting warranty reserves
Constant service interruption rate	MTTSI (mean time to service interruption)	Total service interruptions divided by total population operating time	Customer perception of constant failure rate; may be an availability measure

There are several equivalent ways of expressing the constant rate measures in Table 1. For example, a constant failure rate of 1 % per year is equivalent to 1,1 10^{-6} h^{-1}, 1 100 FITs, 0,01 failures per unit per year, 1,1 failures per million hours, and 10 failures per 1 000 products per year (assuming replacement, 9,95 failures per 1 000 products per year without replacement).

6.2.3 Repaired and non-repaired item concepts

Specifying a single value, such as MTTF, is not sufficient for a product that exhibits a time-dependent failure rate.

This standard considers similarity analysis for the constant failure rate case as well as for non-constant failure rate. IEC 61649, IEC 61710 and IEC 60300-3-5 give details on statistical methods for non-constant failure rate, including Weibull analysis.

Situations may also occur when repaired items, which are restored to functionality after failure, are not repaired to a ‘good-as-new’ condition and so exhibit a non-constant failure intensity. IEC 60300-3-5 provides guidance on non-constant failure rate and non-constant failure intensity. MTTF should be used in case of non-repairable items and MTBF should be used in case of repairable items.

Generally it is recommended to state the failure probability, $F(t)$, of the item instead of stating MTBF or MTTR; however, if MTTF is used it should be used for non-repaired items and MTBF used for repaired items.

6.2.4 Methods for estimating reliability

The following is a list of methods commonly used for assessing reliability:

- similarity analysis;
- durability analysis;
- handbook methods.

The main benefit of a reliability assessment is the identification of the major contributions to system failure, rather than the accuracy of the absolute prediction. The identification of the sources of unreliability supports the prioritisation of actions and allows modifications to be made to the design at an early stage. This is especially important if components, modules or design solutions are reused from previous products. In this case the assessment method estimates the failure rate to be expected if improvement activities are not made. The accuracy of any prediction is determined by the quality of the data and their similarity to the proposed design and its usage and environment.

Unless new technology is being considered, a reliability assessment should be based on appropriate in-service data that are available. Data may be obtained from a number of sources. In order of preference, they are as follows:

- the same or similar equipment used in the same or similar operational, physical and support environment;
- data derived from physical and engineering analysis across the range of environmental conditions in which it will be used;
- test data or field data from component or module suppliers;
- data from industry or generic sources. Generic data sources need to be used with great caution and with lower confidence in the reliability assessment until such time as they can be replaced with better data.

There are many generic and industry specific data sources to support reliability assessments.

This standard describes a number of alternative reliability assessment methods that can provide failure rate data from an equipment level down to a functional or piece part level. When selecting a particular methodology for a specific application, a review of the accuracy and limitations of the approach to provide a justification for its usage should be documented. This justification should include the uncertainty and confidence factors associated with the results of the assessment method.

This standard does not address software issues but only covers methods for hardware items. However, it can be used for hardware items that contain embedded software. Reliability of the embedded software and its interaction with the hardware must be addressed, which may change the original reliability information.

7 Management of reliability assessment process

7.1 Purpose of reliability assessment

7.1.1 General

There are numerous reasons for assessing reliability of an item. Figure 1 illustrates some examples of the activities that require a reliability assessment as an input. For example, to calculate the spares provision for an item in the field, knowledge of the item's failure rate and exposure time would be necessary.

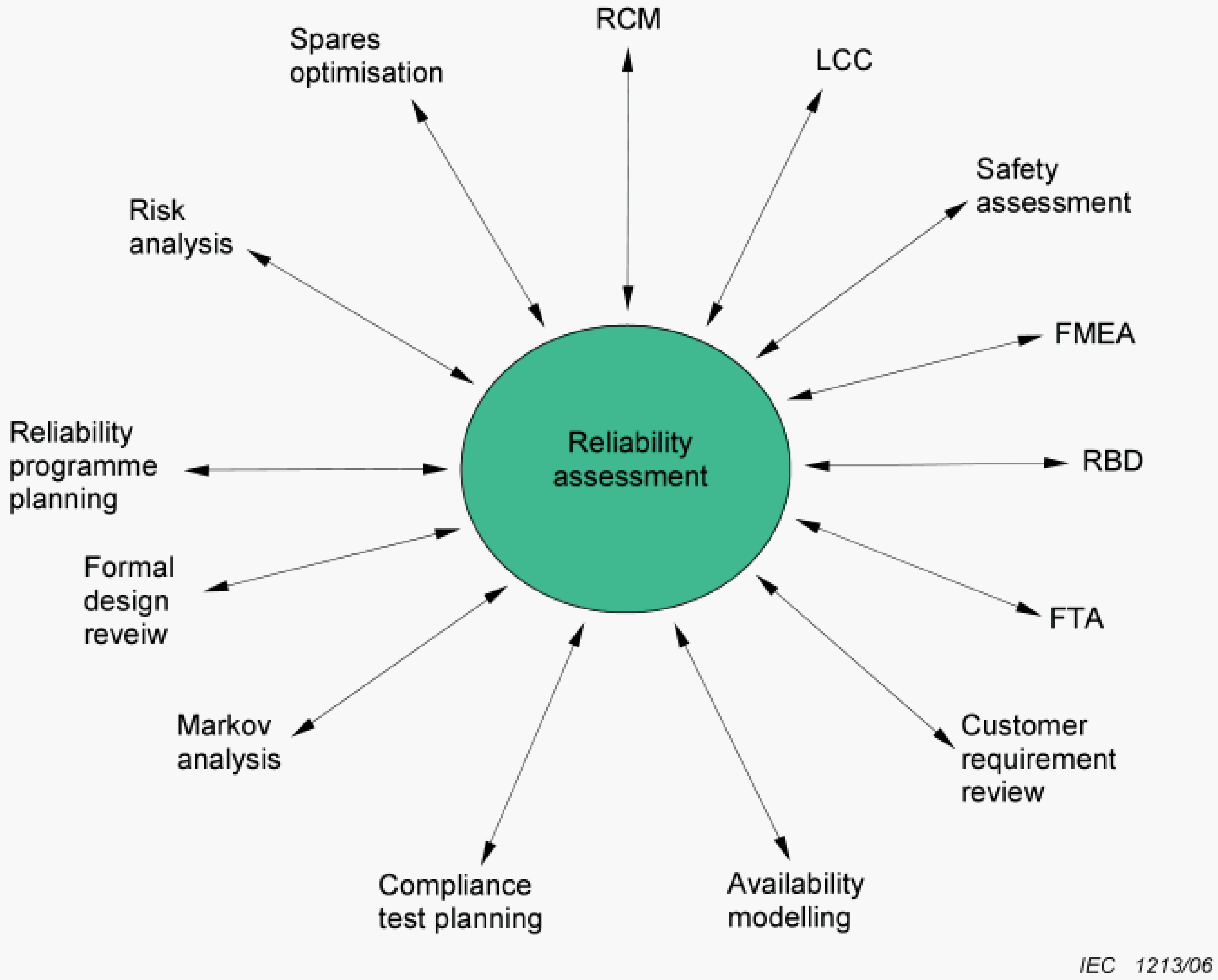

Figure 1 – Methods requiring a reliability assessment as input

Table 2 presents the IEC references for standards on the methods that require reliability assessment as an input.

Table 2 – IEC Standards providing guidance on methods

Method	IEC standard
Analysis techniques for dependability – Guide on methodology	IEC 60300-3-1
FTA	IEC 61025
FMEA	IEC 60812
RBD	IEC 61078
Requirements	IEC 60300-3-4
Design review	IEC 61160
Availability modelling	IEC 61078
Spares provision	IEC 60300-3-12
R&M programme plan	IEC 60300-1
Risk analysis	IEC 60300-3-9
Reliability Centred Maintenance	IEC 60300-3-11
Software dependability	IEC 61713
LCC	IEC 60300-3-3
Safety assessment	IEC 61882
Markov techniques	IEC 61165
Functional safety	IEC 61508
Reliability prediction	IEC 62380

A reliability assessment may be needed to fulfil the following tasks:

a) Reliability goal assessment – Reliability assessments are used to help assess the probability that the system can satisfy its reliability goals (feasibility study).

b) Comparisons of designs and products – Most systems have design implementation options. Tradeoffs have to be made among the various options, and reliability assessment is an important input to these tradeoffs. These options may even affect the system architecture, e.g. the amount and level of redundancy. Since tradeoffs often have to be made early in the design process, the reliability assessment may be very preliminary. However, it is still useful since the important information may be the relative reliability and ranking of design choices rather than a precise quantitative value.

c) Method to identify and prioritise potential reliability improvement opportunities – Reliability improvement activities should generally focus on the areas with the greatest opportunity for improvement. A reliability assessment quantifies the opportunity by identifying the relative reliability of various units and by predicting the reliability improvement obtained from a reliability improvement activity.

d) Logistics support – Reliability assessments are a key to deciding on spare part provisioning policy and estimating the costs of a warranty policy. They can also be used for the first estimate of life cycle costs.

e) Determining the interval for 'failure finding' and 'function testing' types of maintenance tasks.

f) Mission reliability estimation – Missions may have multiple phases with different equipment configurations, and system reliability models can be used for a first estimate of the potential reliability for the entire mission.

One further important factor when assessing reliability is ‘when’, i.e. at what stage in the product life cycle. To assess item reliability it is crucial to start estimating early in the product life cycle and update such assessments as more information becomes available, e.g. from test. Similarly if the assessed reliability is not acceptable, then improvement activities have to be started as early as possible in the product life cycle to ensure reliability improvements. Thus, reliability assessment and monitoring reliability growth (see IEC 61014) is crucial to the correct use of reliability assessments.

Reliability assessment results are typically used for:

– business decisions;
– system architecture decisions;
– equipment design decisions;
– safety analyses;
– reliability programme planning and monitoring.

7.1.2 Business decisions

Examples of business decisions that rely heavily upon the results of reliability assessment include warranty decisions, maintenance cost guarantees and profit sharing agreements, planned design updates, spares provisioning, maintenance scheduling, budgeting and staffing. Applicable measures may be expressed in cost of ownership terms such as service delay and cancellation or operator maintenance burden.

Since business decisions often involve proprietary, sensitive or confidential cost information, reliability assessment reports for these decisions should be carefully controlled and may be maintained separately from results for other purposes. Furthermore, the degree that this information is shared between business entities (e.g. customer, supplier, user) should be the subject of business or contractual agreements.

Prior to the selection of a reliability assessment method a number of criteria have to be considered; these include

– the desired uses of the assessment (*why*);
– the appropriate time in the system life cycle to perform the assessment (*when*);
– which business entity can most capably perform the reliability assessment (*who*);

- the item(s) for which the reliability assessment is to be performed (*what*); and
- the factors that should be considered in selecting the appropriate reliability assessment method (*how*).

7.1.3 System architecture decisions

System architecture is the high-level description, in functional terms, of the structure chosen to satisfy the design specification. This high-level description ensures that system objectives are understood by all interested parties, all relevant factors are considered in the design, all elements of the design are defined and understood at the appropriate level, all elements of the design are evaluated correctly, and alternative solutions are considered.

Examples of system architecture decisions that can be supported by assessment results are as follows:

- fault tolerant design and built-in test; e.g. test method, coverage, or frequency;
- top level hardware and/or software functional partitioning;
- functional partition between modules (block diagram);
- redundancy needs; and
- maintenance support for prognostics.

7.1.4 Equipment design decisions

Examples of equipment design decisions that should be based upon reliability assessment include, but are not limited to”

- system design, comparing hardware technologies, e.g. digital processor, digital logic array versus analogue;
- comparing circuit architecture alternatives;
- comparing utilization, duty cycle, or electrical stress derating alternatives;
- selecting or eliminating certain components;
- deciding on the level of component integration (ASIC-discrete);
- comparing packaging and assembly technology, e.g. surface mount versus through-hole;
- comparing environmental management techniques, e.g. vibration damping and cooling; and
- identifying and correcting design deficiencies in a timely manner based on field and test data of similar components, modules and design.

As with system architecture decisions, the reliability assessment results should be used to substantiate equipment design decisions.

7.1.5 Safety assessment

Safety assessment is the disciplined approach to identifying system hazards and their causes, and to assessing their risks. Safety assessment relates to the reliability assessment of safety-related functions and components. An output of reliability assessment is failure rate, which is often used in various analyses for safety assessment, for example

- fault tree analysis (FTA);
- Markov analysis;
- event tree analysis;
- FMEA; and
- FMECA.

Generic and industry data sources are often used to provide the base failure rate data in system safety assessment. However, this document describes a number of alternative reliability assessment methods that can provide failure rate data from equipment level down to functional or piece part level. (For system safety analysis, the ability to assess the reliability of specific functions is particularly important.)

NOTE IEC 61508 deals with functional safety issues.

7.1.6 Reliability programme planning and monitoring

Reliability assessment results may be used as deliverables at various milestone points in the product design, development, production, and service life cycle. Reliability programme planning should include reliability assessments based on various activities carried out at different stages in the cycle (examples include assembly screening planning, reliability development test planning and reliability verification test planning). Quantitative reliability measures such as MTTF, MTBF, failure-free operating period, time to failure, reliability growth management goals and reliability acceptance requirements should also be identified. Documentation should be produced to ensure that sufficient analysis and/or testing is conducted so that these measures can be produced with the accuracy and confidence required to support reliability programme planning decisions and update estimates in a timely manner. Bayesian statistics may be used to reduce required test sample sizes if the basis of the prior distribution is considered acceptable from an engineering point of view.

Figure 2 shows the stages of the product life cycle and how a reliability assessment may be required at each stage of the process both as an input and as an output.

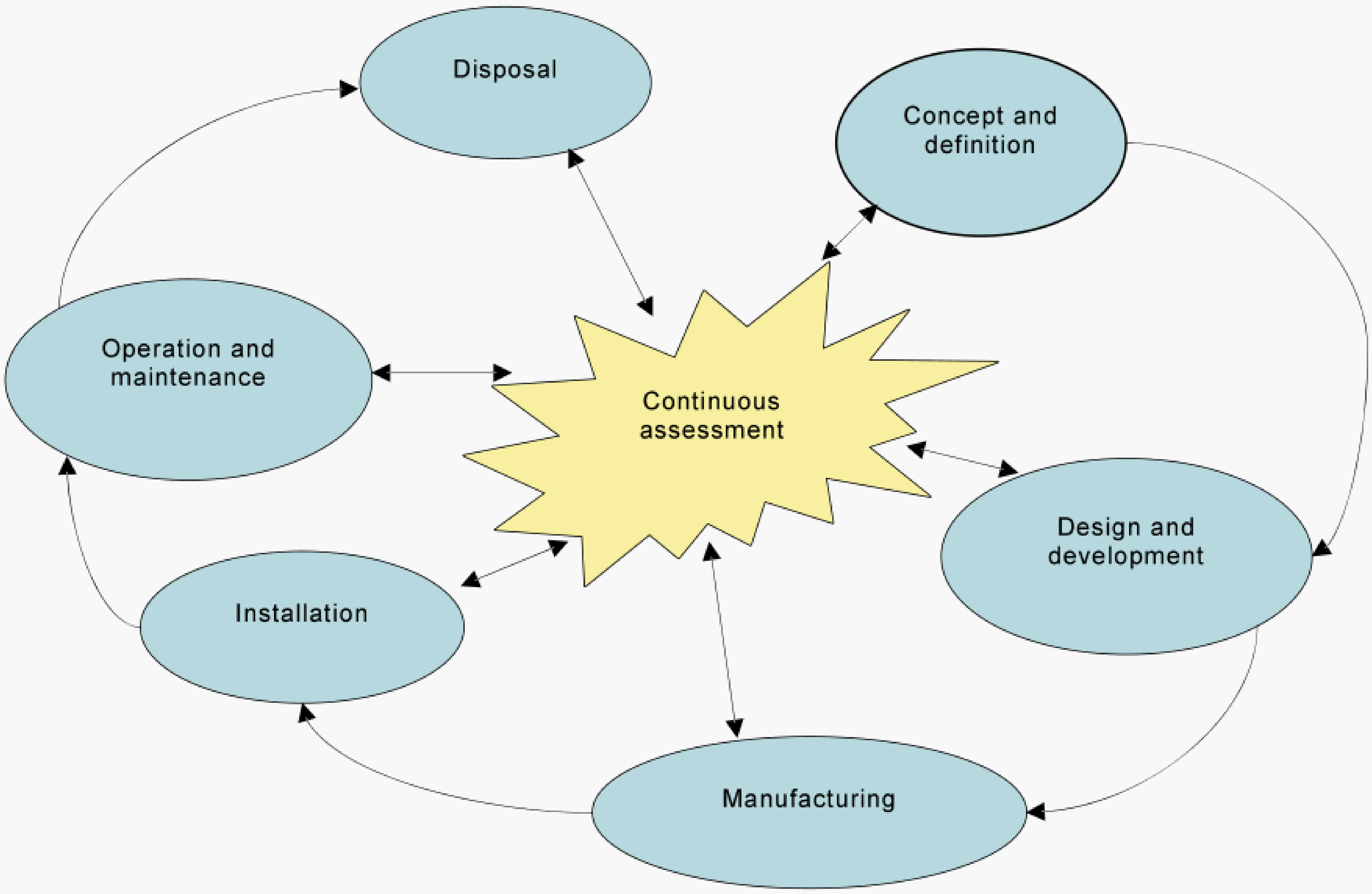

Figure 2 – Stages of product life cycle

The key life-cycle phases include:

- concept and definition phase

  The concept and definition phase is the life-cycle phase during which the need for the product is established and its objectives specified. During this phase, the foundation is laid for the product's dependability and its life-cycle cost implications. Decisions made during this phase have the greatest impact on the product performance functions and ownership costs, but are often given the least consideration;

- design and development

  The design and development phase is the life-cycle phase during which the system architecture, hardware and/or software are created. The relevant product information is captured and documented to facilitate subsequent hardware manufacturing and assembly, software coding and replication, and system integration. Detailed design and qualification follow initial design and this is when the components are defined and sized, stress analysis is undertaken, production plans are developed and software designed;

- manufacturing phase

  the manufacturing phase is the life cycle phase during which the product is produced, the software is replicated, and the system components are assembled;

- installation phase

  the installation phase is the life cycle phase during which the product is put in place for application and operation. The activities involve system installation, maintenance support functions integration, and new product introduction of the installed hardware and software for field trials. The integrated system or end product is put through its performance demonstration in actual operating environments prior to final acceptance for operation;

- operation and maintenance phase

  the operation and maintenance phase is the life-cycle phase during which the product is used for its intended purpose to provide performance operation. Where applicable, the product is maintained for its continual operation in performance functions;

- disposal

  the disposal phase is the life-cycle phase during which the product is terminated from use, removed from its operation site, dismantled, destroyed, recycled or, where appropriate, put in storage.

The reliability assessment methodologies that are described in this International Standard may be used in any phase of the system life cycle, as long as the required engineering information is available. However, because of the progressive nature of the system life cycle, there may be times when certain reliability prediction methods are preferred due to the type and quality of the available engineering information. For example, field data necessary for a reliability prediction based on the information usually becomes available in the production/support phase. Once in service, analysis of service performance increasingly replaces any other method of reliability assessment, provided the data is of good quality and relevant. However, field data from similar in-service systems or component suppliers can be used for reliability predictions earlier in the life cycle.

7.2 Documentation

Reliability assessment results should be reported with sufficient information to understand their uses, limitations, and uncertainties.

The documentation for reliability assessment results should include two types of information, namely:

a) system description;

b) the process of assessment and its results.

The system description should include the following information:

1) equipment description – this should briefly describe the system's physical characteristics;
2) system boundary – this should describe the system's boundary. Block diagrams provide a good method of illustrating the boundary of the system under consideration;
3) usage – this should describe the system's primary role or function, and any secondary roles. It should include its typical operational mission;
4) environment – this should describe the system's operating environment;
5) Interfaces with other equipment – this should define the equipment associated with the inputs, outputs and services to the system. Where appropriate, it should also describe the equipment physically near to the installed system;
6) build standard or the number of the product version – the documentation should relate to a specific build standard of the system;
7) personnel skill levels and training – the skill level and the training should be described;
8) maintenance policy – this should describe the support regimes for each of the system's roles or operating profiles.

Details of conducting the assessment should also be documented and should include

- justification of selection method;
- selection process for the data sources;
- description of calculation methods;
- derived failure rates;
- description of any assumptions;
- details of consultations during the activity (e.g. user, maintainer, designer);
- results of the assessment;
- conclusion and recommendations.

The reports should be controlled and accessible.

8 Data needs

8.1 Input data

Data used in reliability assessment should be obtained from credible and relevant sources and should be controlled, updated, accessed and used according to consistent processes. Data may be obtained from equipment, sub-assembly or component testing, suppliers of COTS, in-service performance and other relevant data sources. A review of the accuracy and completeness of data used should be conducted so that it can be reported in the assessment documentation.

8.2 Data sources and types

The data sources that may be used as inputs to reliability assessment processes should be described. As a general rule, data from product manufacturing and service are highly preferred over data obtained from general industry sources, provided that the population of data is sufficient to carry out a credible statistical analysis. Specific data captured directly from equipment and component suppliers and component assessment using manufacturing techniques is preferred over general industry data because specific failure rate information for a system, sub-assembly or piece part will implicitly reflect the design and manufacturing process capability of the individual equipment supplier. Note that in the case of COTS components the only data available may be from suppliers and this should be used like any other component supplier data.

A description of the process, based upon sound statistical evidence, that defines how the data is selected using the most appropriate data source for the particular assessment application should be produced prior to reliability assessment.

Data include:

a) in-service data from similar equipment and similar applications;

b) in-service data from components and sub-assemblies in similar equipment and similar applications;

c) qualification test data from components and sub-assemblies;

d) quality assurance test data from components and sub-assemblies;

e) development test data from engineering;

f) functional test, and acceptance test data from production; and

g) test and rework data.

Examples of data from other sources include

1) data from component manufacturers (including COTS components);

2) data from industry and consortia databases; and

3) data from handbooks.

The types of information may include

- failure mode;
- failure mechanism;
- fault site;
- maintenance action;
- fault indication and confirmation (BITE data);
- failure effect or criticality including loss of function and any effects of secondary damage;
- operating and environmental conditions to which the item is nominally subjected and those at which the failure occurred;
- hours or cycles to failure of the equipment or sub-assembly in which the failure occurred;
- corrective actions for the failure;
- failure analysis results, including root cause;
- total population exposure time or cycles;
- prognostic data – information about how the item can fail.

It is essential to select data that will enable calculation of appropriate pre-determined reliability measures.

Although the type of data described above is desirable for assessing product reliability, it is not always available.

IEC 60300-3-2 provides more detailed information on data collection.

8.3 Data collection, storage, and retrieval

Data elements are usually integrated into a larger database, as opposed to a separate reliability assessment database. If this is done properly, all relevant data, including lessons learned, are available to design and manufacturing personnel for use on current and future equipment. When using field data for the purposes of reliability assessment, it is crucial to understand the accuracy of the data and the integrity of the data collection process itself, i.e. a good valid and verifiable data collection process is necessary. For example, when using field data to predict a critical failure rate, for a safety analysis, it is necessary to ensure that source data is current, complete and provided by a collection process that focuses on capturing all pertinent data.

Limitations in both the scope of recording and accuracy of reporting data have to be understood. Clearly for the purposes of data analysis, the time to failure of an item would be seen as infinitesimal if the level of its test coverage were insufficient to detect particular faults. The same analysis would result if faults were detected but not reliably reported. In particular, confidence in data is critical when determining unit safety as it often involves two faults, of which the first may be dormant.

When defining the scope of the data collection procedure, consideration should be given to the ability of the procedures to detect and record those failures that subsequent data analysis may be used to predict. A description of those procedures that ensure controlled, repeatable data collection should be documented.

9 Reliability assessment methods

9.1 Introduction

Reliability assessments should be conducted using documented, controlled, and repeatable methods and techniques, which may include analyses or testing. Collecting and using filed data in reliability assessments is recommended, provided the data is of sound quality (see 8.2). These methods should undergo some form of validation. Documentation should include the results of validation carried out to indicate the accuracy and limitations of each method. This information may be used to determine the applicability of an assessment method to a particular reliability assessment activity. Continued validation of each assessment method will be available in the form of in-service data. Current correlation between predicted and actual reliability performance can be provided to justify the selection of a particular method for any subsequent assessment, taking credit for any proven process improvements. Guidelines for managing reliability assessment validation and improvement are detailed in 11.2.

More than one method may be applicable to an item. In fact, it may be advantageous to apply more than one method to a single product in order to establish a representative reliability assessment. Documentation of the justification for the selection of the particular assessment method(s) should be produced. The justification process should also be given, and it should include sound statistical evidence that can demonstrate that the data source and method are applicable to the assessment application in question. Figure 3 shows the reliability assessment process as well as the reliability assessment improvement process.

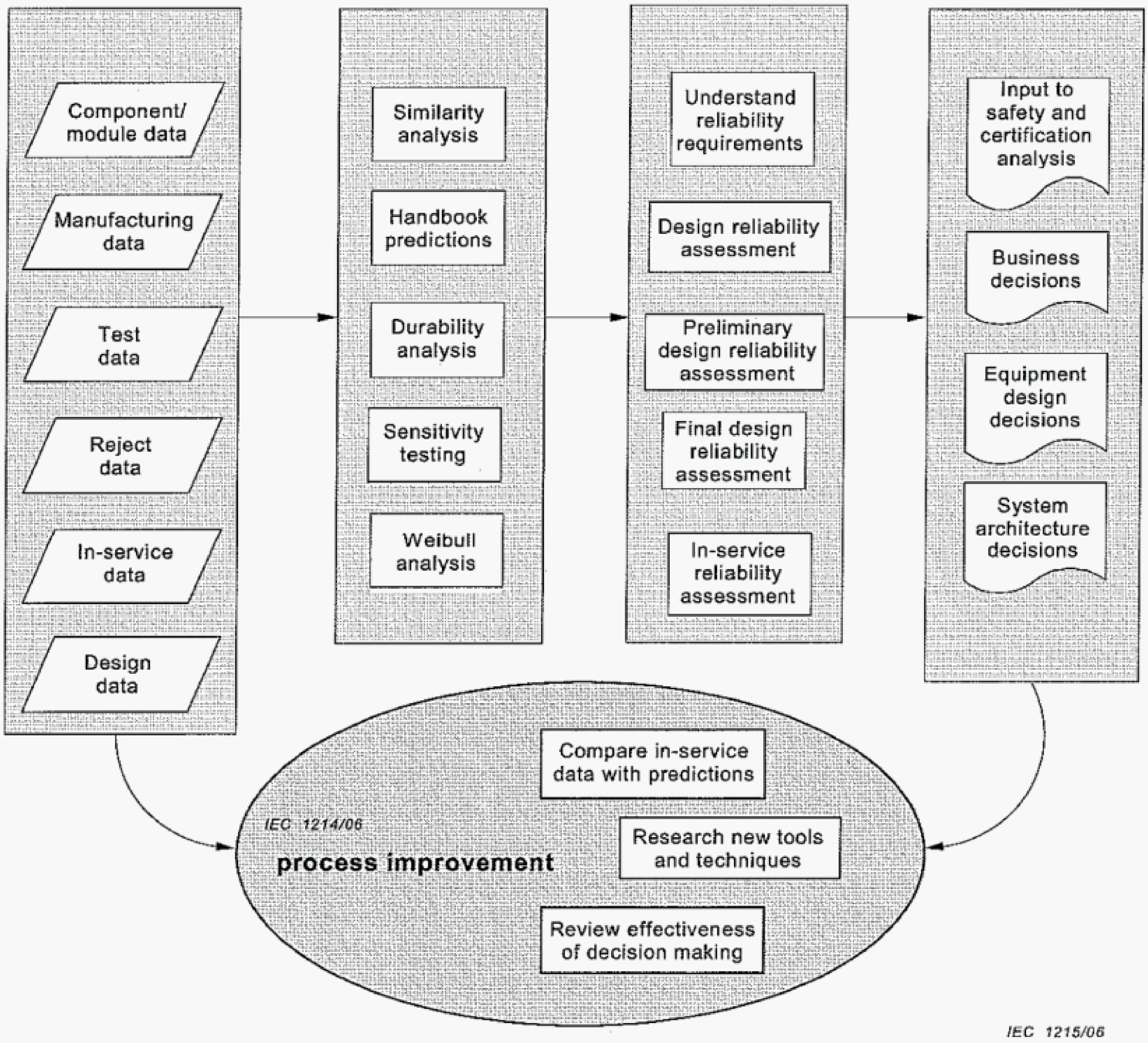

Figure 3 – Reliability assessment and improvement process

9.2 Similarity analysis

9.2.1 Overview of similarity analysis

Similarity analysis includes the use of in-service equipment performance data to compare newly designed equipment with predecessor equipment for estimating end-item reliability when the uses and stresses are similar. Annex A offers guidelines in the form of examples of this method.

Although the concept of similarity analysis is based very much on locating a 'similar' design, it is critical to identify 'differences' between them for further analysis and test. This makes the methodology effective. Similarity analysis done at concept or early design stages enables lessons learnt from similar products performance to be incorporated, or problems eliminated in the new product, leading to improved reliability.

Comparisons of similar equipment may be made at the end-item, sub-assembly, or component level using the same field data, but applying different algorithms and calculation factors to various attributes, described below. Comparison with similar equipment may also be made at the functional level to provide base failure rate data for safety analysis or architectural decision-making.

Attributes to be compared may include:

a) operating and environmental conditions (measured and specified);

b) design features;

c) design processes;

d) design team experience with similar designs;

e) manufacturing processes, including quality control;

f) manufacturer's experience with similar components and processes;

g) built-in test and fault isolation features;

h) test and maintenance processes;

i) components and materials;

j) date or other measure of technology maturity; and

k) quality of the reliability assessment processes.

For each of the above attributes, a number of lower level attributes should be compared. As examples, operating and environmental conditions may include steady-state temperature, humidity, temperature variations, electrical power, duty cycle, mechanical vibration, etc. Equipment design features may include number of components (separated according to major component family), number of circuit card assemblies, size, weight, materials, etc.

Similarity analysis should include necessary algorithms or calculation methods used to quantify the similarities and differences between the equipment being assessed and the predecessor equipment.

When an end-item similarity analysis is not possible because no predecessor equipment is sufficiently similar or available for a one-to-one comparison with the newly designed equipment being assessed, then a similarity analysis may be conducted at a lower level (e.g. sub-assembly, module or component level). The lower level analysis may include the structured comparison of elements of the new equipment with similar elements of a range of different predecessor equipment, for which reliability data are available.

A sample checklist that may be used to facilitate an effective similarity analysis and concise results report is given in 9.2.2.

9.2.2 Similarity analysis checklist

The following items are recommended for inclusion in a product reliability assessment report, which uses the similarity analysis method.

General information

1) analysis date;

2) analyst's name;

3) approvals – As required;

4) programme phase;

5) usage of results.

References

6) applicable reliability assessment plan document;

7) reliability assessment procedure document, (alternatively, procedure may be included in the analysis portion of the report document.)

8) predecessor data archive.

Product identification

9) name of new product;

10) part number of new product;

11) name of predecessor product(s);

12) part number of predecessor product(s).

Analysis

13) level of analysis (LRU, SRU, functional, etc.);

14) predecessor product data summary(ies);

15) attributes compared – consider usage and operational profiles;

16) basis for quantifying attribute differences;

17) algorithm or calculation method(s);

18) identify elements of new design with no previous similar product and how this will be assessed.

Results

19) reliability assessment measure(s) (MTTF, failure rate, etc.);

20) expected variability of reliability measure(s);

21) reliability measure(s) (if applicable).

9.3 Durability analysis

9.3.1 Overview of durability analysis

Durability assessment is used for estimating the life time (time-dependent failure rate) of limited life components. Durability assessment may include analysis and testing, or a combination thereof. It is a structured process that may, as appropriate, include the following major steps.

a) determine operational and environmental loads that the equipment will experience throughout its life, including shipping, handling, storage, operation, and maintenance (extremes and typical or average values should be determined);

b) determine transfer functions between applied loads and boundaries of physics-of-failure approaches, for example box to circuit card, vibration resonances and damping;

c) determine the magnitudes and locations of significant stresses using for example FEA;

d) determine the likely failure sites, mechanisms and modes using for example FEA;

e) determine how long the significant stresses can be withstood or sustained using the appropriate physics-of-failure damage models, e.g. Arrhenius equations, inverse power laws, etc. (overstress analysis at extremes of loading and wear-out analysis at typical/average loadings);

f) report the results as a list of failure sites, mechanisms, and modes; rank-ordered according to the time expected for failure to occur.

Results from accelerated test methods are recommended as sources of test data for input to the durability assessment or a validation method for the damage model whenever possible.

The durability assessment process should be capable of evaluating, as a minimum, the long-term effects of thermal, vibration, and electrical stresses. Capability for other stresses, such as humidity, should be included as necessary. It is highly desirable that the assessment be capable of evaluating the effects of a number of stresses simultaneously. Physics-of-failure models can be useful for this purpose.

The necessary information can often be found from test results and design guidelines from suppliers of components and modules.

In some cases it may be difficult to provide an overall reliability assessment for equipment that contains many devices, each with multiple failure modes. In these cases, durability assessment may be used effectively at a lower level, to analyse specific failure modes and mechanisms within the equipment, which cannot be represented by a constant failure rate. The results of this analysis may then be used as part of a higher level analysis, to assess the reliability performance for the overall equipment. Durability is primarily concerned with wear out processes and so it will not be expected to predict constant failure rates.

A sample checklist that may be used to facilitate an effective durability assessment and concise result report is shown in 9.3.2; more information is provided in Annex B.

9.3.2 Durability assessment checklist

The following items are recommended for consideration for inclusion in a product reliability assessment report, which includes the durability analysis method.

General information

1) analysis date;

2) analysts name;

3) approvals – As required;

4) programme phase;

5) usage of results.

References

6) applicable reliability assessment plan document;

7) durability assessment procedure document;

(alternatively, procedure may be included in the analysis portion of the report document.).

Product identification

8) name of product to which assessment applies;

9) part number of product to which assessment applies.

Analysis

10) identify applicable operational, usage and/or environmental stresses;

11) identify transfer functions and their source (test/analytical or both);

12) identify magnitude and locations of stresses;

13) identify likely failure sites, mechanisms and modes;

14) identify expected life using appropriate damage model(s).

Results

15) identify how analysed failure modes will impact overall reliability measure(s);

16) expected variability in assessment results.

9.4 Sensitivity testing and analysis

9.4.1 Overview of sensitivity testing and analysis

When item failure rates are dominated by a few well understood failure modes, then a structured accelerated test process can support reliability assessments.

Step-stress testing is gaining popularity as a sensitivity test. Its goal is to produce failures in a short time in order to determine the likely failure mechanisms. It will also provide information about design margins with respect to operating and environmental stresses. It is performed on a small sample of the near-final product or a sub-assembly thereof. In some specialized instances, step-stress testing is known by various other names such as HALT (highly accelerated life testing), RET (reliability enhancement testing), and others.

Design marginality to loads and environment can be assessed by use of physics-of-failure analysis or by testing, in particular step-stress testing. Both methods will give assurance to the sensitivity of the design and identify probable failure modes, although any failures may be assessed for relevance under actual service conditions. This analysis and testing cannot always provide a reliability assessment but can be very useful in supporting the assessment and in enhancing product reliability.

Step-stress tests are conducted by exposing the units under test to relatively low levels of stress, and then increasing those levels in a controlled, stepwise manner until at least one of the following occurs.

- stress levels are reached that are significantly higher than those expected in service;
- all the test units fail irreversibly or cannot be repaired;
- irrelevant failures begin to occur or dominate, as new failure mechanisms become evident at higher stress levels. Irrelevant failures are those which are not associated with the design of the test unit, such as test equipment failure, handling damage, or defects in the production of the test unit.

Step-stress tests may or may not supply quantitative data, but they will identify failure modes and estimate design margins. Data from such tests can however be used to remove failure modes from the reliability assessment if the test has shown that the failure mode is no longer relevant in the design, or if an adequate design margin has been achieved.

A sample checklist that may be used to facilitate an effective sensitivity analysis and concise result report is shown in 9.4.2.

9.4.2 Sensitivity testing and analysis checklist

The following items are recommended for inclusion in product reliability assessment reports, as appropriate, which use the sensitivity testing and analysis method.

General information

1) analysis date;
2) analyst's name;
3) approvals – As required;
4) programme phase;
5) usage of results.

References

6) applicable reliability assessment plan document;
7) sensitivity testing and analysis procedure document;

    (Alternatively, procedure may be included in the analysis portion of the report document.)

Product identification

8) name of new product;
9) part number of new product.

Test/analysis

10) failure modes investigated;

11) identify item's operational and usage profile;

12) test methodology and its basis;

13) test results;

14) statistical method for conversion of test results for use in reliability measure(s).

Results

15) impact of results on reliability measure(s);

16) expected variability in reliability measure(s).

9.5 Handbook predictions

9.5.1 Overview of handbook predictions

If no other better data can be obtained, then handbook prediction may be used to supplement data collected by other means. It should be noted that since handbook data are based on industry-wide field and test data, they are an average over many different product fields, product types and applications. Due to the time delay in collecting, analysing and publishing, the data are often based on components that have become obsolete. Attention must therefore be given to the appropriateness of the handbook as well as its revision date. Furthermore, handbook data does not take into account the specific product area, environment or the design methodology and assembly processes for the item to be assessed. Therefore similarity data from similar products and from the components or module suppliers are always preferable to handbook data.

Handbook predictions are made by following the directions in the handbooks chosen for use, or in the software used for implementing handbook predictions.

It is expected that the appropriate handbook will be selected for each application. Handbook users should ensure the applicability and currency prior to use.

IEC 61709 provides guidance on the use of failure rate data for predicting the reliability of components in electronic equipment.

MIL-HDBK-217 is outdated and no longer updated. Industrial associations and companies from all industries have collected and issued data sources, which are useful for undertaking dependability and risk assessments[1].

The accuracy of any prediction is determined by the quality of the data and their similarities to the proposed design, its usage and the environment. Therefore, generic data sources need to be used with great caution and with lower confidence. A better source of data may be obtained from the item supplier. A sample checklist that may be used to facilitate an effective handbook prediction and concise results report is shown in 9.5.2. Note that it is generally more useful to do a part stress analysis rather than a parts count analysis since the part stress analysis takes into account design rating and expected environment for the item being assessed.

9.5.2 Handbook prediction checklist

The following items are recommended for inclusion in a product reliability assessment report, which uses handbook prediction method:

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1 These industry and generic data sources include; TR332-Bellcore Issue 6, SR332-Telcordia 2001, IEC 61380, RDF 95 French Telecom, UTEC 80810 (CHET 2000), HRD – British Telecom, GJB299 Chinese Standard, IRPH93 – Italtel, ALCATEL, RADC 85-91, NPRD-95, and NSWC-98.

General information

1) analysis date;

2) analyst's name;

3) approvals – As required;

4) programme phase;

5) usage of results.

References

6) applicable reliability assessment plan document;

7) reliability prediction handbook;

8) reliability prediction procedure document;

8a) applicability;

8b) currency;

8c) changes from handbook method (if applicable);

(alternatively, procedure may be included in the analysis portion of the report document.)

9) tools used to implement handbook prediction (if applicable);

Product identification

10) name of new product;

11) part number of new product.

Analysis

12) level at which prediction is performed;

13) applicable input data for handbook method;

14) the item's usage and operational profile.

Results

15) reliability prediction measure(s) (MTTF, failure rate, etc.);

16) expected variability in reliability measure(s);

17) reliability measure(s) (if applicable);

18) list all assumptions made for the prediction (rating, environmental factors, duty cycles, quality factors, etc.).

9.6 Limitations of reliability assessment results

Limitations and uncertainties should be quantified, if possible. The statistical significance, based upon the population of the source data and including appropriate confidence intervals, should be detailed to highlight any uncertainty and limitation of reliability assessment results. If limitations and uncertainties cannot be quantified, they should be described concisely, in sufficient detail for the user to understand them and to apply them appropriately.

For those applications where an absolute failure rate is essential, such as for input to a system safety analysis or cost model, only quantified data should be used.

Uncertainties arise when the results are subject to variations in manufacturing processes, components and materials, e.g. variations in a component output or a material property that may affect the equipment's susceptibility to failure. Uncertainties also arise when relationships among factors are not completely known; e.g. if the actual number of operating hours for an MTTF estimate are not known, and have to be in part estimated, then the statistical level of confidence in the result will be reduced.

If a reliability estimate differs significantly from the measured in-service performance of similar equipment in similar applications, then the measure of uncertainty in the result will be recorded as part of the validation process described in 11.2. The output from this ongoing validation activity can then be used in the selection of the most appropriate assessment method for any subsequent analysis, based upon the most current understanding.

10 Considerations for selecting reliability assessment methods

Input data is an important criterion for selecting appropriate reliability assessment methods, but there are also the following factors that may influence the choice:

– technology

  technology may influence the selection of a reliability assessment method in several ways. If the product technology is similar to that used in previous products, reliability assessment methods that make use of historical data or analyses may be appropriate. If the product technology is new, it may be necessary to develop new models;

– consequences of system failure

  the desired reliability assessment precision is a function of the social or business consequences of a system failure. In general, the higher the risk, the higher is the desire for accurate predictions, where risk includes business, technical and social risk. The risks refer to: financial losses caused by delays in acceptance, fines emanating from regulatory requirements, delay in time to market, loss of customer confidence, costs and results of litigation, safety, information privacy, and security. Social risk refers to the potential for human injury or environmental disruption;

– failure criticality

  Fault of an item contained in a system does not necessarily imply system failure. The consequences of the failure modes of each items can, depending on the conditions, be variable, ranging from system failure to unnoticeable. The probability of occurrence of each failure mode can also be variable. It is important to spend more resources evaluating those failure modes with the most severe consequences of failure and/or the highest probability of occurrence;

– available resources

  the choice of reliability prediction method may be affected by available resources, including time, budget and information. Some reliability prediction methods may require engineering information or data that is unavailable, e.g. historical or test data. Time or budget limitations may prevent necessary data from being gathered. The skill levels and familiarity of the available personnel with certain prediction types may influence reliability prediction method selection;

– external influences

  external influences may impact the selection of a reliability prediction method. An organization may have a specified reliability prediction method used for all products or all products of a certain type. Alternatively, customers and regulators may dictate the type of reliability prediction method used or may require a precision that can only be obtained by certain methods. In addition, a bias for or against certain types of prediction methods on the part of the customers or the development organization may influence the selection of reliability prediction method. The available information on operating environment and profile may limit the applicable reliability prediction methods. The selection of a reliability measure may also limit the applicable reliability prediction methods since some methods are useful for only certain types of measures, e.g. constant failure rate. The engineering information available from a supplier may only support certain types of reliability prediction methods, or a supplier may only have the capability to perform certain types of reliability prediction methods;

– quality and availability of data

  reliability data is often imprecise because historical information is not always known accurately, and because the data gathered for a particular system or equipment may not be applicable to other cases for example, where environment, manufacturing quality, failure definition or some other factor or combination of factors differ. This potential inaccuracy has to be recognized and allowed for in the selection of the reliability assessment method;

– contractual requirement

  reliability requirements in contracts often carry penalties for failing to meet these objectives. Suppliers of highly reliable equipment are often able to satisfy these objectives with little design or manufacturing effort, but incur difficulty and expense demonstrating the requirements to the customer. It is often not possible to construct a reliability demonstration which combines sensible risks for both parties with a reasonable length of test. In these situations acceptance of reliability may be based on the accumulated usage of previously installed similar systems or perhaps a guaranteed period where failure costs and/or redesign costs are borne by the supplier. A reliability assessment is often required as part of this type of demonstration. It is desirable that the data source and the reliability assessment method are agreed between the two parties or else various failure rate negotiations will ensue, each party seeking to turn the result in their favour.

11 Reliability assessment process improvement

11.1 General

Previous reliability assessment results could be used to improve the later reliability assessment processes, and are a source of information for improvement of the equipment throughout the equipment life cycle.

11.2 Validating reliability assessment results

Types of validation include:

a) comparing calculated results from reliability assessments, e.g. MTTF, MTBUR, confidence intervals, time to failure, etc., with in-service data;

b) comparing failure sites, modes, and mechanisms predicted by reliability assessments with those obtained from in-service data;

c) checking to ensure that all failures recorded are what might be termed 'legitimate'; and

d) comparing in-service environmental, operating, and maintenance conditions with those assumed in reliability assessments.

Note that a) and d) must be taken account of. With regard to a), it might be that a sudden surge in voltage on a power supply line (a primary failure) arising from the failure of a single component, might lead to many other failures (secondary failures). Unless there was some special reason to record secondary failures, such failures would normally be discounted. Other types of failure might also need to be discounted. For example if the ambient temperature of a piece of equipment rises or falls well beyond design limits, and this in turn gives rise to failure of the equipment, such a failure might well need to be discounted. It should be noted that in some highly reliable pieces of equipment, the vast majority of so-called equipment failures could be traced to causes that had nothing to do with the design or reliability of the equipment.

With regard to b), care should be taken when comparing predictions with observed results. It is almost certain that predictions and observations will never agree exactly or even approximately in spite of the fact that the results of the prediction might be close to reality. This is because predictions are based mainly on *mean* values whereas observations seldom are. For example if an unbiased coin is tossed 10 times, the chance that half the tosses will result in heads and the other half in tails, will be quite small (less than 25 %). Needless to say in repeated runs each of 10 tosses, the proportion of runs consisting of exactly five heads and five tails, will approach 50 %.

The schedule for reporting results from the validation activity should be described and documented.

11.3 Improving the reliability assessment process

In order to improve the reliability assessment process using reliability assessment results, the following should be considered (see Figure 3):

- improvements to the data collection process;
- improvements in the selection of appropriate data source and method for a given assessment application;
- modifying the equations, algorithms, and calculation methods;
- adoption of developing reliability assessment methods from both industry and research establishments and academia provided that they are applicable for the item's application;
- identifying further predecessor equipment for similarity analysis modelling; and
- improved guidance for interpreting assessment results for effective decision making.

Processes should be in place for data collection and analysis, or systems in place to use factory data, customer reject data, and in-service data to improve the design and manufacturing processes for equipment improvement, e.g. FRACAS, reliability growth, reliability enhancement, and statistical process control. The processes that are documented should build on those processes and add information for improving the reliability assessment process, rather than replace or supersede them.

Annex A
(informative)

Similarity analysis examples

NOTE This annex provides information to aid in understanding the similarity analysis method for reliability assessment. It presents example implementations of the similarity analysis method.

A.1 How to use this annex

The choice of the most appropriate reliability assessment method for any given application depends on product type, reliability objectives and available data. In addition, there are many ways to implement similarity analysis, and the most appropriate method and implementation should be selected.

This annex includes descriptions of the data required (see A.2.2), an example of the method (see A.2.3), use and limitations of results (see A.2.4), and reliability assessment process improvement (see A.2.5).

Although the example in this annex addresses calculation of MTTF, it also could be used for other reliability measures.

A.2 Example similarity analysis

A.2.1 General

Two implementation options for similarity analysis are described. These two options are referred to as: high-level and low-level similarity analyses. The primary difference between the two options is that a higher level of similarity is required for the high-level similarity analysis. To show the versatility of the similarity analysis method, the high-level example will be performed at the LRU level and the low-level example will be performed at the functional level, though either method can be applied at any level.

A.2.2 Data

A.2.2.1 In-service reliability data

In-service data collection and analysis are foundations of the similarity analysis methodology. The in-service reliability data typically includes the number of in-service failures, information on failure causes or failure modes, and operating hours.

The first two pieces of information are available from the company database that contains information on all repair activity. The database should identify the specific equipment (end-item or assembly) being repaired, as well as component replacements and a narrative field for maintenance personnel to identify end-item failure types. End-item failures may result from hardware failures, software failures, customer abuse, design errors, manufacturing errors, and other causes. These data are used to calculate failure mode distributions for a product or assembly.

Operating hour data are collected from customer records or estimated from typical utilization rates. These records are maintained in accordance with company practices. These data combined with the failure information, described above, are used to calculate the field failure rates and MTTFs of products or assemblies.

A.2.2.2 Product characteristic data

Product characteristic data are obtained from both in-service end-items and end-items that are under development. The data consist of all the documentation that defines the end-item, as well as information defining the design process, manufacturing process and end-use environment. Examples of end-item documentation are requirement documents, electrical and mechanical parts lists, and layout drawings. These data are used to identify characteristic differences between new and predecessor end-items. A listing of potential characteristic differences is shown in Table A.1.

A.2.3 Methods

NOTE The process steps, spreadsheets, and calculations used in the example similarity analysis methods are described in the following subclauses. Figure A.1. contains an overall flowchart for this process.

A.2.3.1 Physical model categories

Similarity analysis uses the physical model categories described in this clause to compare new and predecessor end-items or assemblies.

The first five categories cited below are part type component level categories that quantify the field failures due to components. The next two categories are design and manufacturing processes. Additional categories may be added for equipment-specific items not related to part type or process categories. In the example below, manufacturing-induced component failures are categorized under manufacturing processes (category 6), and component misapplication and overstress are categorized under the design processes (category 7). The following categories are cited as examples of a physical model:

category 1 low complexity passive parts (resistors, capacitors and inductors);

category 2 high complexity passive parts (transformers, crystal oscillators and passive filters);

category 3 interconnections (connectors, flex tape, printed wiring boards and solder joints);

category 4 low complexity semiconductors (discretes, linear ICs and digital ICs);

category 5 high complexity semiconductors (processors, memory and field programmable gate arrays, application-specific integrated (ASICs) circuits);

category 6 manufacturing process;

category 7 design process; and

category 8 other failure causes, which are specified by the user to describe failure mechanisms that do not fit into categories 1 to 7, or which the analyst wishes to track separately due to high frequency of occurrence. Examples are life-limited failure modes such as lamp or switch life, and specific hardware or software modifications performed as a corrective or preventive action.

A.2.3.2 Process steps

A.2.3.2.1 General

Figure A.1 contains a flowchart of the process steps for similarity analysis. Descriptions of each process step with applicable references to the example spreadsheets of Tables A.2 and A.3 follow.

a) **Step 1:** Compare the new equipment with equipment for which in-service data exist. This can be done at the end-item or the assembly level. If it is done with multiple predecessor end-items or at the assembly level, then the remaining steps may need to be performed individually for each predecessor end-item or assembly.

The output of this step is the identification of one or more end-items or assemblies, which are sufficiently similar to the new equipment, or its assemblies, that comparable levels of reliability are anticipated. Sufficient similarity is determined on the basis of the analyst's knowledge of the equipment involved, the relevant reliability drivers, and experience with the process. Process experience may indicate that, if the number of differences exceeds a specified number, reliability assessment results are no longer usable.

b) **Decision block:** If a high degree of similarity is found between the new and predecessor item, either at the device or assembly level, then a high-level similarity analysis would be the appropriate choice. In this case continue with steps 2H-5H (see below). The remaining process steps and equations for the high-level similarity analysis are described in A.2.3.2.2.

   If insufficient similarity is found to perform a high-level similarity analysis, a low-level similarity analysis approach may still be used. Proceed with steps 2L-5L to perform a low-level similarity analysis if the comparison in step 1 has identified that field data for a group of predecessor products have sufficient similarity to the new product. A high level of similarity is not required for conducting a low-level similarity analysis but greater levels of similarity will improve the assessment accuracy by reducing variability. The remaining process steps and equations for the low-level similarity analysis are described in A.2.3.2.3.

A.2.3.2.2 High-level similarity analysis process steps

Step 2H: Identify all characteristic differences between the new and predecessor end-item or assemblies. A description and example list of characteristic differences is provided in A.2.3.1. Each characteristic difference is entered into the first column of the example spreadsheet shown in Table A.2.

Use of the spreadsheet in Table A.2 is affected by the number of predecessor end-items used, or if the analysis is being performed at an LRU, assembly or functional level. If multiple predecessor end-items are analysed, a separate spreadsheet should be completed for each predecessor end-item. If an assembly or functional level analysis is performed, a separate spreadsheet should be completed for each predecessor assembly or function.

Step 3H: Evaluate each characteristic difference, identified in step 2H above, relative to the expected reliability difference between the new and predecessor item. This evaluation is quantified relative to the individual physical model categories defined in A.2.3.1.

In this step an entry is made for each category of each characteristic difference, as shown in Table A.2. If no impact is expected for a particular characteristic difference in that category, then no entry is necessary (a "1" is assumed). Entries that are expected to improve reliability are less than one, and entries that are expected to degrade reliability are greater than one.

To clarify the entry for the characteristic difference in Table A.2 further, "combined A2 into ASIC" describes the combination of a number of individual components into a single ASIC.

Step 4H: Incorporate the in-service failure data for the predecessor end-item or assembly into the spreadsheet of Table A.2. The in-service failure data, described in A.2.2.1, have to be compiled in the form of percentages to quantify the failure mode distribution, by physical model category and an overall failure rate.

For the failure mode distribution, the causes for all in-service failures, of the end-item or assembly, are assigned to the physical model categories. The failure quantity in each category is then divided by the total failure count to quantify the percent contribution of each category to the total end-item or assembly failure quantity. These percentages are entered into the row in Table A.2 labelled "Predecessor product failure mode distribution". The overall failure rate for the end-item or assembly is entered into the appropriate space in the lower section of Table A.2.

Step 5H: Compile the results in the spreadsheet of Table A.2 to calculate the predicted reliability data. Calculations performed in the spreadsheet are as follows.

a) calculate the values in the row labelled "Products of physical model impacts" for each physical model category, as the product of the entries for all characteristic differences;

b) calculate the values in the row labelled "Failure rate impact per category" for each physical model category, as the product of the "Products of physical model impacts" and "Predecessor product failure mode distribution";

c) calculate the "Failure rate ratio" entry as the sum of all entries in the row labelled "Failure rate impact per category";

d) calculate the "Projected failure rate" for the new end-item or assembly as the product of the "Predecessor failure rate" and the "Failure rate ratio";

The spreadsheet depicting the high-level similarity analysis implements equation A.1:

$$\text{New product failure rate } (\lambda) = \lambda_P \sum_{N=1}^{7} (D_N F_N) \qquad \text{(A.1)}$$

where

λ_P is the field failure rate for the predecessor end-item or assembly;

D_N is the failure mode distribution percentage for category N;

F_N is the difference factor between the new and predecessor end-item or assembly for category N;

N is the physical model category identifier, which ranges from 1 to 7.

The above equation (A.1) is based on the assumption that there are no additional user-defined physical model categories. If there are additional categories, then the maximum value of N increases by the number of user-defined categories.

Though not shown in the spreadsheet, individual category failure rates can be computed. This is accomplished by normalizing the "Failure rate impact per category" entries to total 1,0 and multiplying a category normalized value by the "Projected failure rate".

A.2.3.2.3 Low-level similarity analysis process steps

Step 2L: After the field-exposed product group(s) are selected, the category failure rates are determined. Generally, these category failure rates can be applied directly to the new product; however there may be instances where the failure rates have to be multiplied, e.g. a new product in an environment different from that of the predecessor. In such instances, the failure rates may be multiplied, with a description of the multiplier and its basis included in the assessment report.

The outputs of this step are the category failure rates with any multiplication applied. They are entered into the spreadsheet of Table A.3 in the row labelled "expected category failure rates".

If different predecessor data are being used for different new product functions, a separate spreadsheet will be required for each set of predecessor data. In a similar manner, if multiple predecessor products are used, the data can either be compiled into a single spreadsheet, or a separate analysis with separate spreadsheets can be used for each predecessor product.

Step 3L: Quantify the number of components, by type, for each of the functional levels identified in the first column of the spreadsheet of Table A.3. The component quantities are put into the appropriate component category, and entered into the spreadsheet.

<u>Step 4L</u>: Quantify and list the manufacturing and design process differences between the new and fielded equipment(s). Table A.1 shows a list of potential differences to be considered for the manufacturing and design processes.

The individual difference factors (multipliers) are themselves multiplied to determine a composite failure rate factor for the manufacturing failure rate, and a composite failure rate factor for the design failure rate. Table A.4 shows the identified process factors and their product for the example analysis.

The total process factors are entered into the first open spaces under the category 6 (Manufacturing process) and category 7 (Design process) columns of Table A.3.

The above description assumes that the failure rates are assumed to be constant (exponential). If these failure rates are not constant, the constant failure rate may be replaced with a distribution of another type, e.g. Weibull. In that case the probability $F(t)$ has to be computerised and summarised, taking into account competing risks. Another method is to use Monte Carlo simulation. Refer to IEC 60300-3-5, IEC 61649 and [22].

<u>Step 5L</u>: Perform the assessment calculations with the spreadsheet shown in Table A.3. The calculations use equations (A.2) and (A.3) shown below and are described as follows:

- calculate the row labelled "sum of category counts" for categories 1 to 5 by adding the entries for each level identified in column 1;
- calculate the row labelled "total category failure rate" for
  - categories 1 to 5, by multiplying the "sum of category counts" row by the "expected category failure rate" row;
  - categories 6 and 7, by multiplying the "process factors" row by the "expected category failure rate" row;
- calculate the "total product failure rate" entry by adding all entries in the row labelled "total category failure rate". This failure rate could then be used to calculate MTTF or other appropriate reliability measures.

$$\text{Total product failure rate } (\lambda) = \sum_{C=1}^{5} \sum_{L=1}^{n} Q_{L,C}\lambda_C + F_M\lambda_6 + F_D\lambda_7 \quad \text{(A.2)}$$

$$\text{Total function failure rate } = \sum_{C=1}^{5}\sum_{L=1}^{n} Q_{L,C}\lambda_C + \left(\sum_{L=1}^{5} Q_{L,C}/P_T\right)(F_M\lambda_6 + F_D\lambda_7) \quad \text{(A.3)}$$

where

$Q_{L,C}$ are the part quantities for function number "L" and component category "C";

P_T is the total number of parts in the device, calculated by:

$$P_T = \sum_{C=1}^{5} \sum_{L=1}^{n} Q_{L,C}$$

L denotes one of the assembly levels listed in the first column of the Table A.3 spreadsheet;

C denotes one of the physical model categories as shown in Table A.3;

n is the number of function levels in the assessment;

λ_C represents the expected category failure rate for component category "C";

F_M represents the process factor for the manufacturing process;

F_D represents the process factor for the design process;

λ_6 represents the expected category failure rate for the manufacturing process – category 6;

λ_7 represents the expected category failure rate for the design process – category 7.

The above equations are based on the assumption that there are no additional user-defined physical model categories. Additional user-defined categories are treated in the same manner as the component categories (categories 1 to 5).

The functional level failure rates shown in Table A.3 do not incorporate the process failure rates for categories 6 and 7. Though not shown in the spreadsheet, this can be accomplished by distributing the process failure rates between the functions. Two possible methods to accomplish this are listed as follows.

a) Distribute based on complexity, i.e. parts count, lead count or component category total failure rate.

b) Distribute based on prior knowledge of problem areas encountered in similar products.

The method for distributing the process failure rate can be different between manufacturing and design. A combination of the two methods can also be used, i.e. distribute based on parts count, then adjust for prior knowledge.

A.2.4 Use and limitations

Results from the similarity analysis reliability assessment method can be directly applied to equipment design decisions, business decisions, system architecture decisions and safety assessment decisions. Applicability as input to safety assessment depends on the safety analysis objectives, and also on the level at which the reliability assessment was performed.

A.2.5 Process improvement

After adequate in-service history has been attained for the product, the field data are compared to the reliability assessment results. Inconsistencies are evaluated for potential process changes. These changes may affect the data collection and analysis process or directly impact the process contained in the plan document.

Table A.1 – Example characteristic differences

PHYSICAL	PROCESS	ENVIRONMENTAL
Critical components	CAD usage	Cooling provisions
Degraded operation	CAM usage	Dormancy factors
Deviations and waivers	Document control	Duty cycle
Durability	Customer training	ESD susceptibility
Electrical stress	Derating and stress analysis	Field application
Expected life	ESS, HASS	Repair environment
False alarms	Field representatives	Use environment
Fault isolation	FMEA	
Functional changes	FRACA/FRB	
Modes of operation	Fault tree analysis	
New software	Reliability development testing	
Percentage reusable SW	Material composition	
Power dissipation	Material quality	
Safety factors	Part obsolescence	
Scheduled maintenance	Part quality	
Technology maturity	Part screening	
Test points	Prototyping	
Volume	Second source suppliers	
Weight	Simulation	
	Software	
	SPC	
	Timing analysis	
	Worst case analysis	

CAD Computer aided design
CAM Computer aided manufacturing
ESD Electrostatic discharge
ESS Environmental stress screening
HASS Highly accelerated stress screening
FMEA Failure mode and effects analysis
FRACA Failure reporting analysis and corrective action
FRB Failure review board
SPC Statistical process control

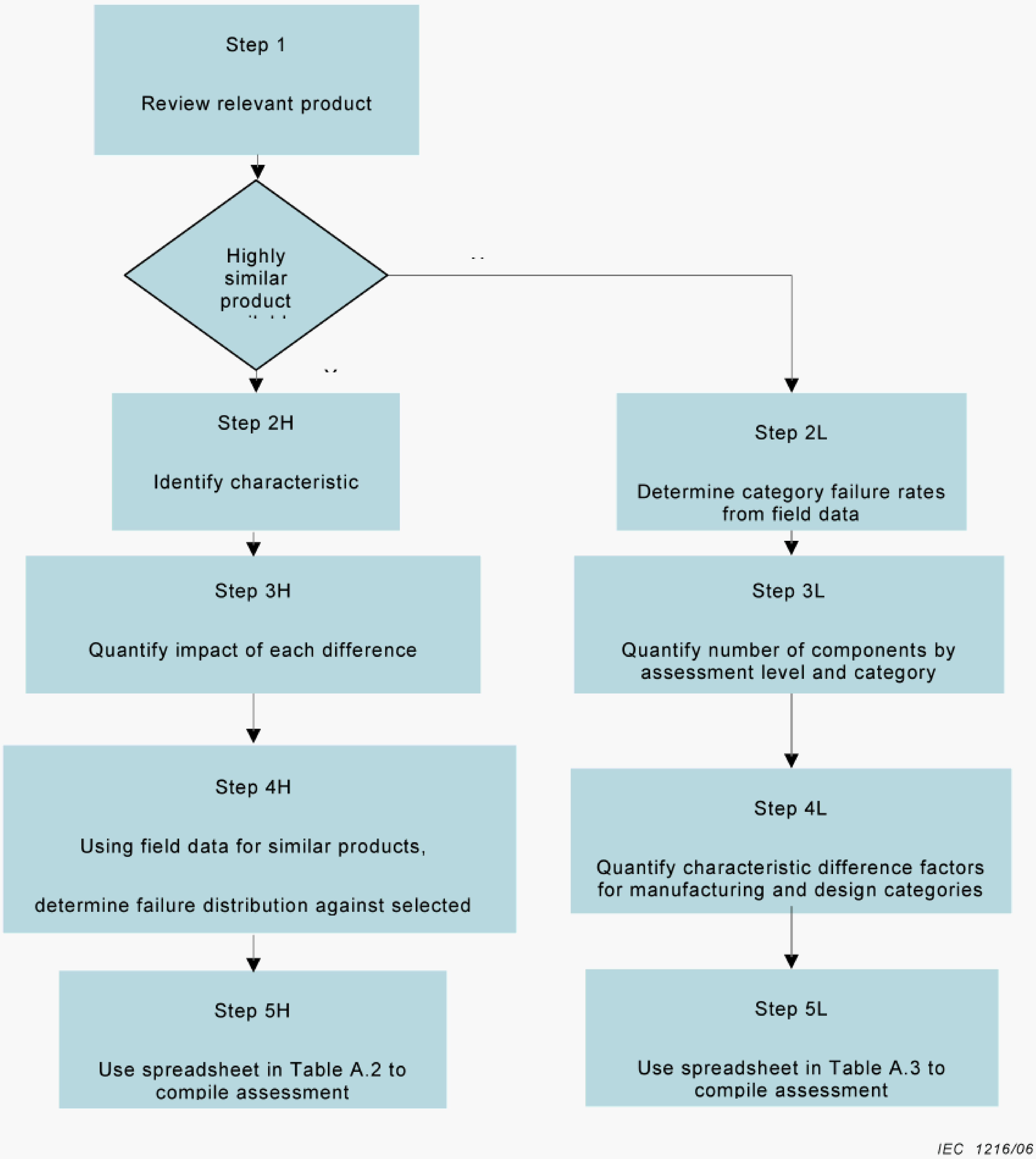

Figure A.1 – Example similarity analysis flowchart

Table A.2 – Example high-level similarity analysis spreadsheet

Product identification: Model YYY	PHYSICAL MODEL CATEGORIES									Predecessor product identification: Model ZZZ
Characteristic differences (Category - Description)	Category 1	Category 2	Category 3	Category 4	Category 5	Category 6	Category 7	Category 8		**Comments**
1.) Two PWB's combined into one			0,9							
2.) Reduced parts count on A4	0,8			0,6						
3.) A1 card moved to surface mount						0,8				
4.) Performing RET on new product							0,8			
5.) Combined A2 into ASIC	0,89		0,98	0,85	1,2					
6.)										
7.)										
8.)										
9.)										
10.)										
PRODUCTS OF PHYSICAL MODEL IMPACTS=	0,712	1	0,882	0,51	1,2	0,8	0,8	1		
PREDECESSOR PRODUCT FAILURE MODE DISTRIBUTION=	10,0%	10,0%	10,0%	20,0%	20,0%	20,0%	10,0%	0,0%		
FAILURE RATE IMPACT PER CATEGORY=	0,0712	0,1	0,0882	0,102	0,24	0,16	0,08	0		
FAILURE RATE RATIO=	0,8414									

Precedessor failure rate (/million op. hrs.) = 50,77
Projected failure rate (/million op. hrs.) = 42,718

Predecessor MTBF (op. hrs.) = 19 697
Projected MTBF (op. hrs.) = 23 409

Table A.3 – Example low-level similarity analysis spreadsheet

Product identification: Model YYY	PHYSICAL MODEL CATEGORIES								Function FR (/million op. hrs.)	Predecessor product identification: Model ZZZ
LRU, Assy. or functional level ID	Category 1	Category 2	Category 3	Category 4	Category 5	Category 6	Category 7	Category 8		Comments
1.) A1 Processor function	12	1	3	6	2				2,204	
2.) A1 Processor memory function	5		1	2	3				2,36	
3.) A2 RS-422 Receiver function	28		3	6					0,806	
4.) A2 UART Function	12		1	3					0,374	
5.) A2 RS-422 Transmitter function	22		3	6					0,794	
6.) A3 115VAC Filter/rectifier function	36	4	2						0,292	
7.) A3 5VDC Regulator function	25	1	1	2					0,33	
8.) A3 +/-15VDC Regulator function	48	1	1	5					0,676	
9.) Chassis signal filter function	16	8							0,272	
10.) Top level (process factors)						0,8	0,9		8,6	
SUM OF CATEGORY COUNTS=	204	15	15	30	5					
FAILURE RATE FACTOR=	1	1	1	1	1					
EXPECTED CATEGORY FAILURE RATE (/million op. hrs.)=	0,002	0,03	0,05	0,1	0,7	4	6			
TOTAL CATEGORY FAILURE RATE (/million op. hrs.)=	0,408	0,45	0,75	3	3,5	3,2	5,4			
TOTAL PRODUCT FAILURE RATE (/million op. hrs.)=	16,708									
PROJECTED MTBF (op. hrs.)=	59 852									

Table A.4 – Example process difference factor tables

Characteristic differences		Impact of manufacturing failure rate
1.	Surface mount versus leaded assembly	0,8
2.	Introduced HASS	0,8
3.	25 % higher board count than average	1,25
4.		
5.		
6.		
7.		
8.		
9.		
10.		
total		0,8

Characteristic differences		Impact of design failure rate
1.	Introduced HALT	0,8
2.	Internal design reviews missed	1,125
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
total		0,9

Annex B
(informative)

Durability analysis

NOTE This annex includes information to help the user understand the durability analysis method of reliability assessment.

B.1 Description and use of durability analysis

Durability analysis is defined as the structured analysis of an item of equipment's response to the stresses resulting from operation, maintenance, shipping, storage, and other activities throughout its specified life cycle in order to estimate its expected life.

As the definition indicates, the results of a durability analysis are stated in expected time to failure, rather than as a failure rate or MTTF. Durability analysis results indicate the length of time an individual item is expected to last prior to failure, rather than the frequency with which a group of items is expected to fail.

Typically, reliability analysis is aimed at assessing the random failures that will occur in the equipment during its useful life. These failures are usually assumed to be repairable, and may be due to a variety of causes, such as defects in the equipment, improper use, damage due to unusual conditions, inadequate maintenance, etc. Durability analysis, on the other hand, assesses failures due to wear-out of certain components in the design.

The major steps of durability analysis are as follows:

a) determination of operating and environmental conditions;

b) stress analysis; and

c) damage modelling.

Each of the above steps is discussed in this annex.

B.2 Durability analysis

B.2.1 Determination of operating and environmental conditions

Durability analysis is concerned with determining the specific responses of the equipment to the specific stresses that the equipment will encounter during its lifetime. For this reason, durability analysis begins with determining the types, magnitudes, and sources of all the conditions in which the equipment have to be operated, stored, or handled.

Operating conditions include:

- electrical stresses due to the function of the equipment;
- steady-state temperature due to self-heating;
- temperature variations due to turning the equipment on and off;
- vibration due to operation;
- moisture conditions due to humidity and condensation; and
- any other stresses that may cause failures.

Environmental stress includes

- ambient steady-state temperature;
- variations in supporting supplies such as power, cooling, etc.;
- variations in ambient temperature;

- ambient humidity;
- ambient chemical contaminants;
- mechanical shock due to handling;
- electromagnetic field;
- maintenance-induced failures;
- mechanical vibration due to transportation; and
- any other environmental conditions that may cause failures.

Some of the conditions described above may be obtained from the customer, and others may be obtained from design handbooks or similar publications. It may not be possible to quantify all the necessary information regarding environmental and operating conditions. In these cases, engineering judgment may be required. If a condition is known, or strongly suspected, to exist, it is usually better to estimate it than to ignore it.

Many of the relevant conditions may occur only in certain phases of the equipment's expected life, such as storage, shipping, etc. It is important to know or estimate credibly the duration of each of the conditions.

B.2.2 Stress analysis

The conditions described above may result in life-limiting stresses in the equipment. Stress analysis is the determination of the magnitudes and locations of those stresses. In some cases, the stresses may be uniform throughout the equipment, e.g. temperature conditions may be uniform when the ambient temperature is stable and the equipment generates little or no heat during operation. In most cases, however, the stresses will vary both temporally and spatially. In almost all cases, the ability of the various elements of the equipment to withstand the stresses will vary.

Usually, stress analysis is conducted with some type of computer-aided analytical process, such as finite element or finite difference analysis. The results of this type of analysis are usually reported graphically, with the areas of greatest stress being highlighted in some easily detectable way.

B.2.3 Damage modelling

B.2.3.1 General

After the types, locations and magnitudes of the stresses are identified, their effect in causing wear-out failures is determined. This is done using damage models. Damage models are mathematical equations that predict how long a given item can withstand a given stress before failure due to wear-out. (Damage models also may be used in accelerated testing to estimate the behaviour of an item over a longer time at a lower stress level, based on its behaviour in a shorter time at a higher stress level.)

As the name implies, damage models are useful for predicting wear-out failures due to the accumulation of damage caused by operating or environmental stresses. They are not applicable to failures due to overstress.

The most rigorous damage models are those that describe the failure mechanisms at the structural, or atomic, level. They are called structural, closed form, constitutive, or physics-of-failure models. An example of such a model is Fick's work in diffusion [1].

Another type of damage model is the empirical model. Empirical models are not based on descriptions of structural changes, but describe mathematically the data collected from testing or use. They can be viewed as curve fitting, although a good knowledge of physics-of-failure mechanisms is often applied to the exercise. Examples of this type of model are some of those developed for humidity testing. Note, however that most damage models have been developed using some level of empiricism.

Damage models range from the very simple to the very complex. Usually, the simpler models can be said to apply to a wider range of cases, while the more complex models are specific to a rather narrow set of applications. Also, some of the more complex models can be quite difficult to use. Engineering judgment is required to select the simplest model that gives satisfactory results. Perhaps the best advice in this regard is that given by Weibull [2]:

> *"......there may exist two or more true relationships of different shapes. Facing this abundance, the only reasonable way to act seems to be to choose the one which most easily gives answers to posed questions."*

A variety of damage model forms is available for durability analysis, and all reasonable models should be considered. In this annex, three general forms are presented:

a) the Arrhenius model;

b) the inverse power law; and

c) the Eyring model.

Most of the popular damage models in use today are variations of one of these three models. They, and other models, are described in many publications, and references [3] to [7] are listed as examples.

The empirical factors for the models are estimated by tests made for each new component technology by the component suppliers. Data can be obtained from the component suppliers, from JEDEC122 or from literature.

B.2.3.2 The Arrhenius model

Svante Arrhenius [8] developed his model in 1889 to describe the inversion of sucrose. The model is a rate equation that gives the temperature dependence of the process rate:

$$r = r_o \mathrm{e}^{-\frac{E_a}{\mathrm{k}T}} \tag{B.1}$$

where

- r is the reaction rate;
- r_o is a constant;
- E_a is the activation energy, in electron volts[2];
- k is Boltzmann's constant ($8{,}617 \times 10^{-5}$ eV/K); and
- T is the reaction temperature, in K.

The product of the reaction rate and the time for it to occur is constant over its temperature range of applicability, or

$$r_1 t_1 = r_2 t_2 \tag{B.2}$$

for two different reaction temperatures T_1 and T_2. Thus for a given mechanism, with time to failure expressed as t_f, rt_f is a constant, and

$$t_\mathrm{f} = \mathrm{Ae}^{\frac{E_a}{\mathrm{k}T}} \tag{B.3}$$

---

[2] Usually, the activation energy is reported in electron-volts, but sometimes it is reported in calories or kJ per mole. 1 eV = 23 kcal/mole = 96,5 kJ/mole.

If the constant A and the activation energy are unknown, they can be determined by conducting an accelerated test at a temperature higher than that expected in use. This yields an *acceleration factor* for the Arrhenius equation:

$$\mathrm{A}F = \frac{t_\mathrm{u}}{t_\mathrm{t}} = \exp\left[\frac{E_a}{\mathrm{k}}\left(\frac{1}{T_\mathrm{u}} - \frac{1}{T_\mathrm{t}}\right)\right] \quad \text{(B.4)}$$

where the subscripts u and t indicate "use" and "test" respectively.

The Arrhenius equation describes thermally-activated mechanisms such as solid-state diffusion, chemical reactions, many semiconductor failure mechanisms, battery life, etc.

The Arrhenius equation is applicable to many failure mechanisms, but a different value of activation energy will apply (in general) for each mechanism.

B.2.3.3 The inverse power law

The inverse power law describes the life of a system that is inversely proportional to an applied stress. Its general form is

$$\tau = \frac{\mathrm{A}}{S^n} \quad \text{(B.5)}$$

where

τ is the time for an event (such as failure) to occur;

A is a constant characteristic of the product;

S is the applied stress; and

n is an exponent characteristic of the product.

Different forms of the inverse power law have been developed for various applications. One of the most common is the Coffin-Manson Law for fatigue testing [9, 10]:

$$N_\mathrm{f} = \mathrm{A}\left(\frac{1}{\Delta\varepsilon_\mathrm{p}}\right)^\mathrm{B} \quad \text{(B.6)}$$

where

N_f is the number of cycles to failure;

A is a constant related to the material;

$\Delta\varepsilon_\mathrm{p}$ is the plastic strain range; and

B is a constant related to the material.

This equation has been modified for a variety of situations [11] to [16]. It applies to both isothermal mechanical fatigue cycling, and to fatigue due to mechanical stresses resulting from thermal cycling. If the total applied stress is much higher than the elastic strain range for a fatigue test, a simplified acceleration factor for isothermal fatigue testing is

$$\mathrm{A}F = \frac{N_\mathrm{fu}}{N_\mathrm{ft}} = \left(\frac{\Delta\varepsilon_\mathrm{t}}{\Delta\varepsilon_\mathrm{u}}\right)^\mathrm{B} \quad \text{(B.7)}$$

where u and t denote use and test. The values of $\Delta\varepsilon$ could be due to displacement in bending, elongation in tension, or other mechanical strains. Similarly, a simplified acceleration factor for fatigue testing in temperature cycling is

$$\mathrm{A}F = \frac{N_{\mathrm{fu}}}{N_{\mathrm{ft}}} = \left(\frac{\Delta T_{\mathrm{t}}}{\Delta T_{\mathrm{u}}}\right)^{\mathrm{B}} \tag{B.8}$$

where the values of ΔT are the applied temperature cycling ranges. Some qualifications on the use of equation (B.7) are noted in reference [14], and for equation (B.8) in reference [16].

Based on testing experience, the approximate values given in Table B.1 are commonly used for the exponent B in equations (B.7) and (B.8).

Table B.1 – Values for exponent B for equations (B.7) and (B.8)

Metals	2 to 3
Electronic solder joints	1 to 3
Microelectronic plastic encapsulants	4 to 8
Microelectronic passivation layers	12
Cratering of microcircuits	7
Al-Au intermetallic fatigue failures	4 to 7

The inverse power law plots as a straight line on log-log paper, with a slope equal to B. This line is called the *S-N* curve.

B.2.3.4 The Eyring model

The Arrhenius equation and the inverse power law each have a single stress term. The Eyring model [18] has two stress terms, one of which is temperature. Its general form is

$$\tau = \mathrm{A}\left(\frac{1}{S}\right)^{\mathrm{B}} e^{\frac{E_a}{\mathrm{k}T}} \tag{B.9}$$

where

τ is a measure of product life;

A and B are constants;

S is an applied stress; and

$E_a/\mathrm{k}T$ is the Arrhenius exponent.

The applied stress, S, can be almost any stress that exists in combination with temperature. It can be used in a variety of transforms, such as $1/S$, $\ln S$, etc. Two commonly used stresses are humidity and voltage. S also can be an additional temperature term, such as temperature cycling range or rate. An example of the Eyring equation is Peck's temperature-humidity relationship for electronic microcircuits [19, 20]:

$$t_{\mathrm{f}} = \mathrm{A}(\mathrm{RH})^{-n} e^{\frac{E_a}{\mathrm{k}T}} \tag{B.10}$$

where

t_{f} is the time to failure;

A is a constant;

RH is the percentage relative humidity;

n is a constant; and

E_a/kT is the Arrhenius exponent,

n and E_a are determined empirically, and may vary from one test situation to another.

Generally, n is equal to 3,0 and E_a is equal to 0,9 eV. The acceleration factor is

$$AF = \left(\frac{RH_u}{RH_t}\right)^{-3,0} \exp\left[\frac{E_a}{k}\left(\frac{1}{T_u} - \frac{1}{T_t}\right)\right] \quad (B.11)$$

In this case, the Eyring model is the product of the inverse power law for humidity and the Arrhenius equation for temperature.

B.2.3.5 Selecting the appropriate damage model

Damage models are, by nature, inexact. The most effective models will usually represent a compromise between the extremes of:

a) attempting to describe the situation so completely that they become so complex and data-hungry that they are unusable, and

b) being so simple that they are inaccurate.

Jensen [21] lists three rules in selecting and using models:

- the underlying assumptions should be clearly stated, realistic and recognizable;
- required data have to represent the real world, and be practical to gather;
- the end result has to be presented in uncluttered terms that clearly represent a solution to the practical problem.

The three general model forms presented above are the most common ones used in accelerated testing, but they are certainly not the only ones. Often, a transform of the applied stress, S, has to be used to accurately describe the failure mechanism. Some commonly used transforms are

$$A(1/S),\ A+B\ln S,\ AS^{B},\ A+B/S,\ 1/(A+BS),\ \text{and}\ A+BS \quad (B.12)$$

In the above discussions, it is assumed that the applied stresses are well defined and constant. Many models describe only a single stress, and ignore the effects of other stresses that are applied simultaneously. In reality, the situation is always more complicated. Every product's operating environment consists of many stresses, which vary in intensity and range during use.

B.3 Reporting durability analysis results

Typically, durability analysis results are reported as a list of likely failures, arranged chronologically from the shortest to the longest time to failure. From a reliability prediction point of view, only the shortest times to failure are of interest. This is because durability analysis predicts wear-out failures, which by definition are common cause; thus all the items will fail by the short time wear-out mechanisms (competing risks). Other uses for durability analysis results, such as equipment design and architectural decisions, may require the inclusion of a longer list.

The type of information reported for durability analysis is not well established. At a minimum, the following information should be included for each failure.

a) **Time to failure.** This is usually a point estimate; however, the distributions of some failures may be known. It may be specified using a Weibull model. Often, suppliers state the time for a given percentage of failures as for example B10 (10 % failed) and B50 (average lifetime).
b) **Failure site.** It is desirable to know which element of the design will fail. In addition to being useful as an input to safety analysis, this information could be useful to the designer in improving the design.
c) **Failure mechanism.** This information also is useful for safety analysis and for design improvement.
d) **Failure-causing stress.** This information can be used to evaluate changes in the operating and environmental conditions to increase time to failure.

Bibliography

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The following list provides information on sources of information that may be of value. This summary is not intended to be an exclusive or definitive list; neither does it represent endorsement or recommendation of the techniques described. The user of this standard is encouraged to assess any method in terms of how well it satisfies the criteria laid out in the main body of the standard and, in particular, the approach described in Clause 1. There are many commercially available reliability software tools available on the market; the decision for an organization is whether to buy an off-the-shelf tool or to develop a tool internally which specifically meets the need of the organization.

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