IEC 61164

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INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Reliability growth – Statistical test and estimation methods

Croissance de la fiabilité – Tests et méthodes d'estimation statistiques

IEC 61164:2004

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CONTENTS

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RELIABILITY GROWTH – STATISTICAL TEST AND ESTIMATION METHODS

FOREWORD

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International Standard IEC 61164 has been prepared by IEC technical committee 56: Dependability.

This second edition cancels and replaces the first edition, published in 1995, and constitutes a technical revision.

The main changes with respect to the previous edition are listed below:

– addition of two statistical models for reliability growth planning and tracking in the product design phase;
– statistical methods for the reliability growth programme in the design phase of IEC 61014;
– addition of the discrete reliability growth model for the test phase;
– addition of the fixed number of faults model for the test phase;
– clarification of the symbols used for various models;
– addition of real life examples for most of the statistical models;
– numerical correction of tables in the reliability growth test example.

This standard should be used in conjunction with IEC 61014.

This bilingual version (2012-03) corresponds to the monolingual English version, published in 2004-03.

The text of this standard is based on the following documents:

FDIS	Report on voting
56/920/FDIS	56/939/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

The French version of this standard has not been voted upon.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until 2011. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This International Standard describes the power law reliability growth model and related projection model and gives step-by-step directions for their use. There are several reliability growth models available, the power law model being one of the most widely used. This standard provides procedures to estimate some or all of the quantities listed in Clauses 4, 6 and 7 of IEC 61014.

Two types of input are required. The first one is for reliability growth planning through analysis and design improvements in the design phase in terms of the design phase duration, initial reliability, reliability goal, and planned design improvements, along with their expected magnitude. The second input, for reliability growth in the project validation phase, is for a data set of accumulated test times at which relevant failures occurred, or were observed, for a single system, and the time of termination of the test, if different from the time of the final failure. It is assumed that the collection of data as input for the model begins after the completion of any preliminary tests, such as environmental stress screening, intended to stabilize the product's initial failure intensity.

Model parameters estimated from previous test results may be used to plan and predict the course of future reliability growth programmes, provided the conditions are similar.

Some of the procedures may require computer programs, but these are not unduly complex. This standard presents algorithms for which computer programs should be easy to construct.

RELIABILITY GROWTH – STATISTICAL TEST AND ESTIMATION METHODS

1 Scope

This International Standard gives models and numerical methods for reliability growth assessments based on failure data, which were generated in a reliability improvement programme. These procedures deal with growth, estimation, confidence intervals for product reliability and goodness-of-fit tests.

2 Normative references

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

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

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

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

IEC 60605-6, *Equipment reliability testing – Part 6: Tests for the validity of the constant failure rate or constant failure intensity assumptions*

IEC 61014:2003, *Programmes for reliability growth*

3 Terms and definitions

For the purposes of this document, the terms and definitions of IEC 60050-191 and IEC 61014, together with the following terms and definitions, apply.

3.1
reliability goal
desired level of reliability that the product should have at the end of the reliability growth programme

3.2
initial reliability
reliability that is estimated for the product in earlier design stages before any potential failure modes or their causes have been mitigated by the design improvement

3.3
reliability growth model for the design phase
mathematical model that takes into consideration potential design improvements, and their magnitude to express mathematically reliability growth from start to finish during the design period

3.4
average product failure rate
average product failure rate calculated from its reliability as estimated for a predetermined time period

NOTE The change in this failure rate as a function of time is a result of the modifications of the product design.

3.5
delayed modification
corrective modification, which is incorporated into the product at the end of a test

NOTE A delayed modification is not incorporated during the test.

3.6
improvement effectiveness factor
fraction by which the intensity of a systematic failure is reduced by means of corrective modification

3.7
type I test
time-terminated test
reliability growth test which is terminated at a predetermined time, or test with data available through a time which does not correspond to a failure

3.8
type II test
failure-terminated test
reliability growth test which is terminated upon the accumulation of a specified number of failures, or test with data available through a time which corresponds to a failure

4 Symbols

For the purposes of this standard, the following symbols apply.

a) For 6.1, Clauses A.1 and B.3:

T	product lifetime such as mission, warranty period or operational time
$R_0(T)$	initial product reliability
λ_{a0}	initial average failure rate of product in design period
$d(t)$	number of design modifications at any time during the design period
α_D	reliability growth rate resultant from fault mitigation
D	total number of implemented design improvements
t_D	total duration of the design period available for the design improvements
t	time variable during the design period from 0 to t_D
$\lambda_a(t)$	average failure rate of product as a function of time during the design period
$\lambda_{aG}(t_D)$	goal average failure rate at the end of the design period t_D

$R_G(T)$	reliability goal of the product to be attained during design period
$R(t,T)$	reliability of product as a function of time and design improvements

b) For 6.2, Clauses A.2 and B.4:

$R_G(T)$	reliability goal of the product to be attained during design period
t_D	total duration of the design period
α_D	reliability growth rate during design period
λ_{NS}	rate of non-systematic (or residual) failures
D	total number of predicted or implemented design improvements within design period to address weaknesses
K	total number of distinct classes of fault
j,k,i	general purpose indicators
p_{kj}	probability of j-th design weakness in fault class k resulting in failure during the specified life of the product
η_k	expected number of design weaknesses in fault class k resulting in failure during the specified life of the product
D_k	total number of predicted or implemented design improvements within design period to address faults in fault class k
λ_k	failure rate of design weaknesses categorized in fault class k
$R_I(T)$	initial reliability at time T
$R(T)$	reliability of product as a function of T
t_G	expected time to reach reliability goal

c) For 7.1.1, 7.1.2, Clauses 9, A.4, B.1, and B.2:

D	total number of design modifications carried out during product design period to mitigate identified faults
t_D	total duration of the design period available for potential design modifications
t	time variable (during design period $0 \le t \le t_D$)
$d(t)$	number of design modifications at any given time t during design period from 0 to t_D
α_D	reliability growth rate during the design period
λ_{a0}	initial average failure rate of a product in design

$\lambda_a(t)$	product average failure rate variable as a function of time during the design period (0 to t_D)
$R_0(T)$	initial product reliability calculated for a time T (mission or other predetermined time)
$R_G(T)$	product reliability goal to be attained through design improvement, calculated for a predetermined time
$R(t)$	product reliability increase as a function of time and design improvements
λ_{aG}	goal average failure rate
T	predetermined time during a product life (mission, warranty, life)
λ	scale parameter for the power law model
β	shape parameter for the power law model
CV	critical value for hypothesis test
d	number of intervals for grouped data analysis
$\overline{E}, E_i, E_j$	mean and individual improvement effectiveness factors
I	number of distinct types of category B failures observed
i, j	general purpose indices
K_A	number of category A failures
K_B	number of category B failures
K_i	number of i-th type category B failures observed: $K_B = \sum_{i=1}^{\ell} K_i$
M	parameter of the Cramér-von Mises test (statistical)
N	number of relevant failures
N_i	number of relevant failures in i-th interval
$N(T)$	accumulated number of failures up to test time T
$E[N(T)]$	expected accumulated number of failures up to test time T
$t(i-1); t(i)$	endpoints of i-th interval of test time for grouped data analysis
T	current accumulated relevant test time
T_i	accumulated relevant test time at the i-th failure
T_N	total accumulated relevant test times for type II test
T^*	total accumulated relevant test times for type I test
$\chi^2_\gamma(\nu)$	γ fractile of the χ^2 distribution with ν degrees of freedom
z	general symbol for failure intensity
u_γ	γ fractile of the standard normal distribution
z_p	projected failure intensity
$z(T)$	current failure intensity at time T (relevant test time)
$\theta(T)$	current instantaneous mean time between failures
θ_p	projected mean time between failures

p_j	probability of success at the stage i of product modification in design phase described in Barlow, Proschan and Scheuer discrete reliability growth model
$N(t)$	number of non-random type faults remaining at time t>0 in IBM/Rosner continuous reliability growth model
g	fraction that a product/equipment is debugged as given in the IBM/Rosner reliability growth model
E	exposure time of item
λ_{NS}	failure rate of non-systematic (residual) failures
λ_S	failure rate of systematic failures
μ_k	failure rate of the k-th failure class
D_k	number of potential design weakness in failure class k
$p_{k,j}$	probability that the j-th potential design weakness associated with failure class k will result in failure
t_E	expected design phase time to achieve goal reliability, $R_G(T)$
t_D	duration of design phase
$R_I(T)$	initial reliability at time T
α	parameter to represent the expected growth rate
λ_k	the expected number of design weaknesses associated with failure class k that will result in failure
K_2	proportion of systematic (non-random) faults in product design at start of test
K_1	number of faults in the product design at start of test
q	fraction of faults removed through debugging on reliability growth test
$q(T)$	fraction of original faults removed by time t
t_q	expected time for removing fraction q of systematic faults in test
$\theta(T)$	cumulative time between failures

d) Symbols used in the discrete reliability growth model, 7.2:

R_i	reliability, or success probability, of the i-th configuration
$f_i = 1 - R_i$	unreliability, or failure probability, of the i-th configuration
k	number of stages and configurations
n_i	number of trials for stage i
m_i	number of failures for stage i
$t_i = \sum_{j=1}^{i} n_j$	the cumulative number of trials through stage i
$N(t_i)$	the accumulated number of failures up through trial t_i
$\mathrm{E}[N(t_i)]$	the expected accumulated number of failure up through trial t_i
λ, β	scale and shape parameters for power law and discrete models

5 Reliability growth models in design and test

The basic principles of reliability growth of a product are the same during design and test. This is because both involve identifying and removing weaknesses to improve the product and both measure that improvement by comparing the estimated reliability with the reliability goal. The difference lies in the tools used to conduct design and test analysis and the models used to measure reliability growth. IEC 61064 provides guidance on the construction of reliability growth programmes and the analysis tools used in design and test. This standard provides details about the models that can be used to measure reliability growth in different stages of the product life cycle and for different types of items, such as repairable or one-shot items.

The mathematical models for reliability growth are constructed to estimate the growth achieved and the projected reliability. Reliability growth models aim to support the planning of reliability improvement programmes by estimating the number and the magnitude of the changes during the design and development process or the test time required to reach a specified reliability goal.

The reliability growth models can be formulated in terms of the failure rate (or intensity) or probability of survival to a specified time (the reliability) as shown in Figure 1.

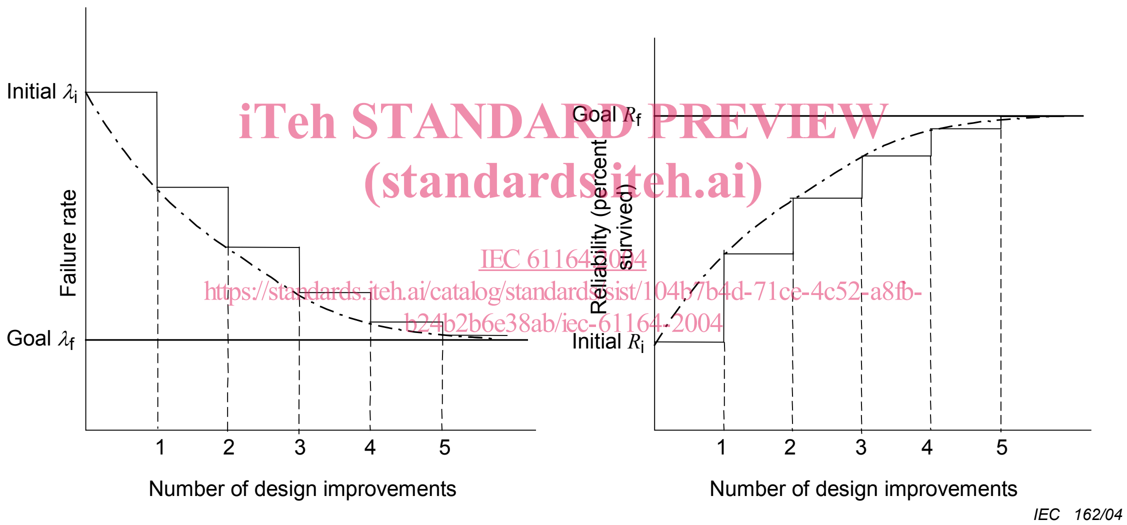

Figure 1 – Planned improvement of the average failure rate or reliability

Within this general framework many models for reliability growth exist. Table 1 provides a summary of the main categories. As well as the distinction between design and test, the type of data available will influence model selection. The continuous category refers to items that operate through time, for example, repaired items. The discrete category refers to data that are collected as if for a success/failure of a trial, for example, one-shot items. The procedures used to estimate reliability growth are labelled classical or Bayesian. The former uses the observed data only, while the latter uses both empirical data from design and test as well as engineering knowledge, for example, regarding the anticipated number of failure modes of concern.

Table 1 – Categories of reliability growth models with clause references

Model type			**Time**	
			Continuous (time)	**Discrete (number of trials)**
	Design	Classical	6.1	–
		Bayesian	6.2	–
	Test	Classical	7.1	7.2
		Bayesian	–	–

Many reliability models have been developed for analysing test data. This standard presents one of the most popular growth models, the power law (also known as the AMSAA or the Crow model) in both its continuous and discrete forms. This model is a generalization of the Duane reliability growth model due to Crow [1][1]. Although Bayesian variants of these models exist, they are not presented here. A review of the variety of reliability growth models available for analysing test data can be found in Jewell [2, 3] and Xie [4].

There are fewer documented reports of reliability growth models being used in design. Therefore a reliability growth planning model that is a modification of the power law for use in design and a Bayesian variant of the IBM-Rosner model adapted for design have been introduced. However, these are only given for products operating through continuous time.

In general, the choice of a reliability growth model involves a compromise between simplicity and realism. Selection should be made according to the aforementioned criteria such as stage of lifecycle and type of data, as well as by evaluating the validity of the assumptions underpinning a specific model for the context to which it is to be applied. Further details about the assumptions for the models described in this standard are given in Clauses 6 and 7. Note that reliability growth models should not be regarded as infallible nor should they be applied without discretion but used as statistical tools to aid engineering judgement.

6 Reliability growth models used for systems/products in design phase

6.1 Modified power law model for planning of reliability growth in product design phase

6.1.1 General

The statistical procedure for the modified power law model for the planned reliability growth in the product design phase concerns the necessary implementation of the design reliability improvements by mitigation of a failure mode, or by reduction of its probability of occurrence, and the time from the beginning of design to that improvement.

This model is used for planning purposes (and not for data analysis), to estimate the number or the magnitude of improvements in the original design to increase its reliability from that initially assessed to its goal value. The assumption of a power law for this model is justified by the fact that the early improvements will be those that will contribute the most to the reliability improvement, that is, the failure modes with the highest probability of occurrence will be addressed first, followed by improvements of lesser and lesser reliability contribution. The actual reliability values achieved in the course of the design are then plotted corresponding to the design time when they were realized and compared to the model. This model is thus used to plan the strategies necessary for reliability improvement of a design during the available time period from the initial design revision until the design is completed and released for production.

[1] Figures in square brackets refer to the bibliography.