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Maintainability of equipment —

Part 6: Guide to statistical methods in maintainability evaluation

Committees responsible for this British Standard

The preparation of this British Standard was entrusted to Technical Committee QMS/23, Reliability and maintainability systems upon which the following bodies were represented:

AEA Technology
Association of Consulting Engineers
Association of Project Managers
British Gas plc
British Railways Board
British Telecommunications plc
City University
Civil Aviation Authority
Consumers' Association
Cranfield University
Design Council
Electricity Association
Federation of the Electronics Industry
GAMBICA (BEAMA Ltd.)
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Royal Institution of Chartered Surveyors
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Safety and Reliability Society
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Contents

National foreword

This Part of BS 6548 has been prepared by Technical Committee QMS/23. It is identical with IEC 706-6:1994 *Guide on maintainability of equipment — Part 6: Section 9: Statistical methods in maintainability evaluation,* published by the International Electrotechnical Commission (IEC).

Six Parts of this standard have been published and these may be summarized as follows.

Part 1: Guide to specifying and contracting for maintainability. This Part introduces the concept of maintainability and provides guidance on the definition of maintainability requirements and on the programmes needed to achieve them.

Part 2: Guide to maintainability studies during the design phase. This Part provides guidance on studies that should be carried out during the design phase and on the relationship of these studies to maintainability and maintenance support tasks. The purpose of the studies is to assist design decision making, to predict the quantitative maintainability characteristics of an item and to help in the evaluation of alternative design options.

Part 3: Guide to maintainability verification and the collection, analysis and presentation of maintainability data. This Part provides guidance on the various aspects of verification necessary to ensure that specified maintainability requirements have been met and outlines suitable procedures and test methods. Guidance is also given on the collection, analysis and presentation of maintainability data.

Part 4: Guide to the planning of maintenance and maintenance support. This Part provides guidance on the planning of maintenance and maintenance support during the system acquisition phase to ensure that availability objectives are met in the operational phase. The interrelationships with reliability and maintainability programmes are also described.

Part 5: Guide to diagnostic testing. This Part provides guidance on consideration of testability characteristics during the design and development of equipment. It will assist in determining effective test procedures as an integral part of operation and maintenance.

Part 6: Guide to statistical methods in maintainability evaluation. This Part provides guidance on statistical methods for use when allocating maintainability requirements to the various parts of a system, and when carrying out maintainability demonstrations and evaluations.

Guidance on many studies closely related to maintainability is also contained in the various Parts of BS 5760 *Reliability of systems, equipment and components.*

Many terms used in this standard are defined in BS 4778 *Quality vocabulary — Section 3.1 Guide to Concepts and related definitions.*

Cross-references

International standard	Corresponding British Standard
IEC 50 (191)	BS 4778 *Quality vocabulary* Section 3.2:1991 *Glossary of international terms* (Identical)
ISO 3534-1:1993	BS ISO 3534-1 *Statistics — Vocabulary and symbols —* Part 1:1993 *Probability and general statistical terms* (Identical)

Reference to sections of IEC 706

The various Parts of IEC 706 each contain one or more sections. References to these sections are sometimes made in the text. The sections are reproduced in the Parts of BS 6548 as follows.

IEC 706 section number and title	Corresponding Part of BS 6548
Section 1 *Introduction to maintainability*	BS 6548-1:1984
Section 2 *Maintainability requirements in specifications and contracts*	BS 6548-1:1984
Section 3 *Maintainability programme*	BS 6548-1:1984
Section 4 *Diagnostic testing*	BS 6548-5:1995
Section 5 *Maintainability studies during the design phase*	BS 6548-2:1992
Section 6 *Maintainability verification*	BS 6548-3:1992
Section 7 *Collection, analysis and presentation of data related to maintainability*	BS 6548-3:1992
Section 8 *Maintenance and maintenance support planning*	BS 6548-4:1993

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 16, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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Introduction

Maintainability engineering is the technical discipline directed towards enhancement of the ease of maintenance of equipment. In the preceding parts of this guide, important methods and techniques are presented which can be used to achieve this objective. Many of them are of a qualitative nature; some, however, include also quantitative aspects, especially for:

— allocating maintainability target values to subitems;

— verifying the fulfilment of quantitative maintainability requirements;

— evaluating maintainability data.

For a complete understanding of these methods and techniques, it is necessary to provide some mathematical explanation to enable the user to apply them more generally.

1 Scope

This part of IEC 706 is being issued as section 9 of the guide on maintainability of equipment. It specifies techniques covering some quantitative aspects of maintainability engineering in various phases of the system life cycle.

This part of IEC 706 is applicable to the tasks of maintainability allocation, maintainability demonstration and maintainability data evaluation, as described in sections 5, 6 and 7, respectively, of the guide (IEC 706-2 and IEC 706-3). In the informative Annex A, Annex B and Annex C, mathematical methods and procedures for performing these tasks are presented in corresponding order. The document is intended to serve as an addendum, for specific maintainability topics, to existing statistical textbooks.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 706. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this part of IEC 706 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 50(191):1990, *International Electrotechnical Vocabulary (IEV) — Chapter 191: Dependability and quality of service.*

IEC 706-2:1990, *Guide on maintainability of equipment — Part 2: Section 5 — Maintainability studies during the design phase.*

IEC 706-3:1987, *Guide on maintainability of equipment — Part 3: Sections 6 and 7 — Verification and collection, analysis and presentation of data.*

ISO 3534-1:1993, *Statistics — Vocabulary and symbols — Part 1: Probability and general statistical terms.*

3 Definitions

For the purpose of this part of IEC 706, the terms and definitions of IEC 50(191), ISO 3534-1 and of preceding sections apply. Additional terms, symbols and acronyms which are used in some of the annexes are defined in Annex A.

4 Mathematical back-up material

The material under this heading is presented in the order of the related sections of the guide. For each of these sections, the problems to be solved by mathematical means are indicated; the mathematical material itself is then given in an annex.

4.1 Material related to Section 5

Section 5 of the guide on maintainability of equipment deals with maintainability studies in the design phase. One of the tasks considered is the allocation of item maintainability requirements to subitems/lower indenture levels. This is an iterative process starting early in the item life cycle on the basis of preliminary design information, and later on updated when more detailed data and information becomes available. An example of the early type of maintainability allocation is given in Annex A of section 5; the underlying assumption in this case is that the subitem maintainability requirement is inversely proportional to the subitem's complexity.

Annex A presents the method recommended for the updating of the early maintainability allocation. This method should be used when additional design data become available, so that the functional breakdown of the item can be carried down to lower subitem levels, with failure rate values allocated to all subitems. The method is applicable to all systems where the assumption of a log-normal distribution of the corrective maintenance time is satisfied, and where sufficiently detailed design information is available, for example, in or at the end of the definition phase. For application of the method, it needs specification of a maximum allowable time for active corrective maintenance.

4.2 Material related to Section 6

In Appendix A of Section 6 of the guide, statistical test methods are identified, which should be applied to verify the fulfilment of quantitative maintainability requirements. Details of these test methods are described in Annex B. They may be applied to all maintainability demonstrations, when the maintenance events are statistically independent. The test conditions should be representative of the actual conditions of use.

4.3 Material related to Section 7

In Section 7 of the guide, aspects of the analysis of maintainability related data which could be obtained from relevant sources (e.g. historical sources, development or demonstration tests, production, assembly, or field operations), and which should be used for maintainability compliance/determination testing, are briefly described. One important part of this analysis is the determination of the data distribution. In Annex C, the most frequently used method for distribution testing, the Kolmogorov-Smirnov test (also known as d-test), is presented. This test is applicable for all types of data and for all distribution forms. For other possible methods (chi-square test, graphical procedures), pertinent statistical textbooks should be consulted.

Annex A (informative)
Maintainability allocation

A.1 Definitions and abbreviations

All definitions in clause **3** also apply to this annex. In addition, the terms, definitions and abbreviations determined in the following subclauses are used:

A.1.1 Definitions

A.1.1.1
active corrective maintenance time
that part of the active maintenance time during which actions of corrective maintenance are performed on an item [IEV 191-08-07]

A.1.1.2
line replaceable unit
functional item which is suited and intended to be removed from the system as part of a single maintenance action on the first (field) line of maintenance

A.1.1.3
maximum active corrective maintenance time
by convention, the 0,95 fractile of the active corrective maintenance time distribution, i.e. that part of the active corrective maintenance time during which 95 % of all actions of corrective maintenance on an item can be accomplished

A.1.1.4
median active corrective maintenance time
that part of the active corrective maintenance time during which 50 % of all actions of corrective maintenance on an item can be accomplished

A.1.1.5
mean active corrective maintenance time
the expectation of the active corrective maintenance time

A.1.2 *Acronyms*

ACMT	active corrective maintenance time
$ACMT_{95}$	maximum active corrective maintenance time
$ACMT_{50}$	median active corrective maintenance time
LRU	line replaceable unit
MACMT	mean active corrective maintenance time

A.2 Maintainability allocation requirements and method

A.2.1 *Requirements*

The maintainability allocation method described below should be applied when sufficient design information is available to carry the functional subdivision of the item considered down to lower indenture levels. It is essential to provide the following information:

— a required or preliminarily predicted value of the item's failure rate λ;

— allocated failure rate values λ_i for all *n* subitems, such that $\sum_{1}^{n} \lambda_i(t) = \lambda$;

— a specified value of the item's mean active corrective maintenance time MACMT (alternatively, the value λ·MACMT may be specified, i.e. the mean active corrective maintenance time multiplied by the item's failure rate λ. λ·MACMT is thus the mean active corrective maintenance time per operational time unit);

— a specified value of the maximum active corrective maintenance time $ACMT_{95}$.

On this basis, required values $ACMT_i$ should be allocated to each subitem i.

A.2.2 ***Method***

The method is base on the assumption that the maintenance times, especially the active corrective part of them, which is generally under the control of the supplier, can be adequately described by a log-normal distribution with mean MACMT and 0,95 fractile $ACMT_{95}$. Active corrective maintenance times longer than $ACMT_{95}$ are determined so as to provide the complement to the accumulated mean active corrective maintenance time specified for the item.

A.3 Maintainability allocation procedure

Step 1 Identify the log-normal distribution (with standard deviation = σ) to be followed. One point in the distribution is originally known: $ACMT_{95}$. Also MACMT, the mean active corrective maintenance time, is given. From

$$\frac{ACMT_{95}}{MACMT} = e^{1,645\sigma - 0,5\sigma^2}$$

and

$$\frac{ACMT_{50}}{MACMT} = e^{-0,5\sigma^2}$$

follows

$$\frac{ACMT_{50}}{MACMT} = \frac{ACMT_{95}}{MACMT} e^{-1,645\sigma} = f\left\{\frac{ACMT_{95}}{MACMT}\right\}$$

Thus $ACMT_{50}$ can be determined (see Figure A.1). This offers a second point in the distribution function, which can now be drawn as a straight line in a log-normal diagram (see Figure A.2).

NOTE Normally this algorithm yields two distinct solutions with different values of the mean and the standard deviation of the underlying log-normal distribution. The distribution to be selected is the one with the smaller coefficient of variation, e.g. in case of the log-normal distribution

$$\left(e^{\sigma^2} - 1\right)^{0,5}$$

Step 2 Identify all LRUs and list them in decreasing order of failure rate:

$\lambda_1 \geq \lambda_2 \geq ... \geq \lambda_i \geq ... \geq \lambda_n$

Step 3 Calculate the relative frequency f_i for each LRU_i:

$$f_i = \frac{\lambda_i}{\sum_{k=1}^{n} \lambda_k}$$

Step 4 Calculate the cumulative frequency function F_i for each LRU_i:

$F_i = f_1 + f_2 + ... + f_i$

Step 5 For each LRU_i, calculate $F_i - \frac{1}{2} f_i$ and find the corresponding value of $ACMT_i$ in the log-normal distribution identified in Figure A.2 for LRU_i with

$F_i - \frac{1}{2} f_i < 0,95$

Step 6 For all LRUs where $F_i - \frac{1}{2} f_i \leq 0,95$, determine

$$ACMT_{i,95} = \frac{\lambda \cdot MACMT - \sum_{i=1}^{1} \lambda_i \cdot ACMT_i}{\lambda - \sum_{i=1}^{1} \lambda_i}$$

where 1 = number of the first unit for which $F_i - \frac{1}{2} f_i \leq 0,95$.

A.4 Example

The item is subdivided in 15 subitems. Item requirements:

$$\lambda = 0{,}0372/\text{OH} = \sum_{i=1}^{15} \lambda_i \qquad \text{(for } \lambda_i \text{ see Table A.1, column 2)}$$

$$\lambda\ \text{MACMT} = 0{,}060\ \text{h/OH}$$

$$\text{ACMT}_{95} = 4{,}0\ \text{h}$$

It follows

$$\text{MACMT} = \frac{0{,}06}{0{,}0372} = 1{,}61\ \text{h}$$

$$\frac{\text{ACMT}_{95}}{\text{MACMT}} = \frac{4{,}0}{1{,}61} = 2{,}48$$

For the log-normal distribution with the smaller coefficient of variation (see note in step 1), the functional relationship to $\frac{\text{ACMT}_{50}}{\text{MACMT}}$ is given in Figure A.1.

Thus

$$\frac{\text{ACMT}_{50}}{\text{MACMT}} = 0{,}78$$

This is the second point of the log-normal distribution plotted in Figure A.2. Now, steps 2 to 5 are performed (Table A.1, columns 2 to 5). Corresponding values of $\frac{\text{ACMT}_i}{\text{MACMT}}$ are obtained from Figure A.2 for subitems 1 to 9 and transformed into ACMT_i -values (Table A.1, columns 6 and 7).

For subitems 10 to 15, step 6 yields

$$\text{ACMT}_{i,95} = \frac{0{,}06 - 0{,}05142}{0{,}0372 - 0{,}0360} = 7{,}15$$

ACMT_i's for these subitems are calculated by multiplication with the respective λ_i values (Table A.1, column 8, summation values column 9). The calculations are presented in Table A.1.

Table A.1 — Maintainability allocation to subitem level

1	2	3	4	5	6	7	8	9
Subitem	$\lambda_i\ 10^6$	f_i	F_i	$F_i - \frac{1}{2} f_i$	$\frac{ACMT_i}{MACMT}$	$ACMT_i$	$ACMT_i \cdot \lambda \cdot 10^3$	$\Sigma\ ACMT_i \cdot \lambda \cdot 10^3$
1	10 000	0,268	0,268	0,134	0,355	0,57	5,70	
2	8 000	0,215	0,483	0,377	0,617	0,99	7,92	
3	5 000	0,134	0,617	0,551	0,847	1,36	6,80	
4	3 000	0,081	0,698	0,659	1,023	1,65	4,95	
5	2 500	0,067	0,765	0,731	1,180	1,90	4,75	51,42
6	2 500	0,067	0,832	0,800	1,400	2,25	5,63	
7	2 500	0,067	0,899	0,865	1,660	2,67	6,68	
8	1 500	0,040	0,939	0,920	2,051	3,30	4,95	
9	1 000	0,027	0,966	0,954	2,512	4,04		
10	500	0,013	0,979				3,58	
11	200	0,005	0,984				1,43	
12	200	0,005	0,989			7,15	1,43	8,57
13	100	0,003	0,992				0,71	
14	100	0,003	0,995				0,71	
15	100	0,003	0,998				0,71	

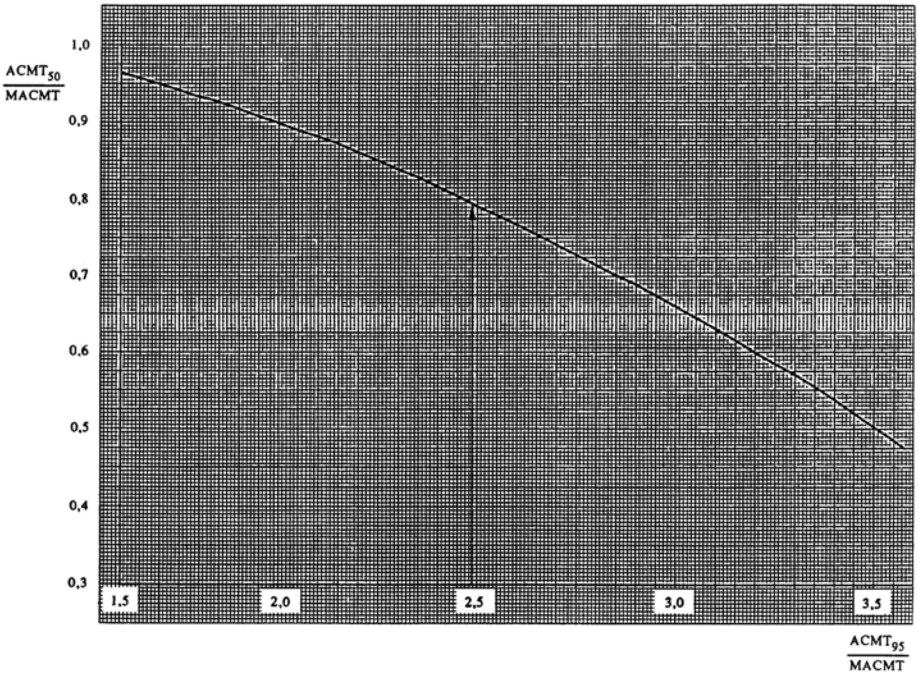

Figure A.1 — $\dfrac{\text{ACMT}_{50}}{\text{MACMT}} = f\left\{\dfrac{\text{ACMT}_{95}}{\text{MACMT}}\right\}$

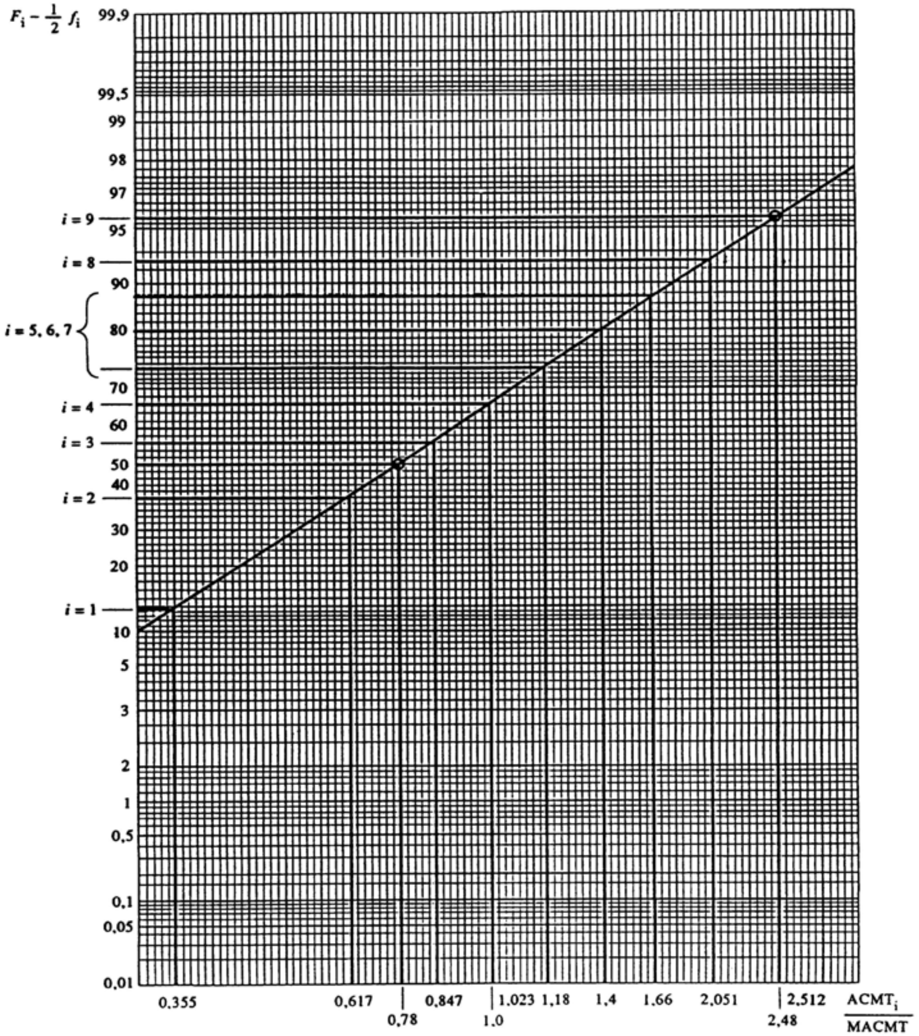

Figure A.2 — Maintainability allocation to subitem level

Annex B (informative) Maintainability demonstration test methods

B.1 Test method 1

Test index: Test on the mean, i.e. MACMT.

Assumptions: Active corrective maintenance time, ACMT, can be adequately described by a log-normal distribution. The variance of the logarithm of ACMT, σ^2, is known from prior information.

Tested hypotheses:
Null hypothesis H_0: mean $\mu \leq \mu_0$
Alternative hypothesis H_1: mean $\mu > \mu_0$

Probability of acceptance, P_a:
$P_a = 1 - \alpha$ for $\mu = \mu_0$
$P_a = \beta$ for $\mu = \mu_1$
α = type I risk, β = type II risk, $\mu_1 > \mu_0$

Sample size, n:

$$n = \frac{\left(u_{1-\alpha}\mu_0 + u_{1-\beta}\mu_1\right)^2}{\left(\mu_1 - \mu_0\right)^2}\left(e^{\tilde{\sigma}^2} - 1\right)$$

where

$\tilde{\sigma}^2$ is a prior estimate of the variance of the logarithms of active corrective maintenance times;

$u_{1-\alpha}$, $u_{1-\beta}$ are standardized normal deviates.

Minimum sample size: 30.

Decision procedure: From a random sample of n active corrective maintenance times

$x_1, x_2, \ldots, x_n$ compute the sample mean $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$

and the sample variance $\hat{d}^2 = \frac{1}{n-1}\left(\sum_{i=1}^{n} x_i^2 - n \cdot \bar{x}^2\right)$.

Accept H_0 if $\bar{x} \leq \mu_0 + u_{1-\alpha}\frac{\hat{d}}{\sqrt{n}}$

Reject H_0 otherwise.

B.2 Test method 2

Test index: Test on the mean, i.e. MACMT.

Assumptions: No specific assumption concerning the distribution of active corrective maintenance times, ACMT, is made. The variance of ACMT, d^2, is known from prior information.

Tested hypotheses: See test method 1.

Probability of acceptance P_a: See test method 1.

Sample size, n:

$$n = \tilde{d}^2\left(\frac{u_{1-\alpha} + u_{1-\beta}}{\mu_1 - \mu_0}\right)^2$$

where

$\tilde{d}^2$ is a prior estimate of the variance of the active corrective maintenance times;

$u_{1-\alpha}$, $u_{1-\beta}$ are standardized normal deviates.

Minimum sample size: 30.

Decision procedure: See test method 1.

B.3 Test method 3

Test index: Test on the mean, i.e. MACMT.

Assumptions: None.

Tested hypotheses: See test method 1.

Probability of acceptance P_a: See test method 1.

Sample size, n:

$$n = \hat{d}^2 \left(\frac{u_{1-\alpha} + u_{1-\beta}}{\mu_1 - \mu_0} \right)^2$$

where

$\hat{d}^2$ is the sample variance of a sample of active corrective maintenance times;

$u_{1-\alpha}$, $u_{1-\beta}$ are standardized normal deviates.

Minimum sample size: 50.

Decision procedure: See test method 1.

B.4 Test method 4

Test index: Test on a fractile.

Assumptions: ACMT is adequately described by a log-normal distribution, σ_2 is known from prior information.

Tested hypotheses: Null hypothesis H_0: $x_p \leq T_0$

Alternative hypothesis H_1: $x_p > T_0$

x_p is the fractile of order p of X, T_0 is the specified time separating the accept and reject regions of the tested time fractile.

Probability of acceptance P_a:

$P_a = 1 - \alpha$ for $x_p = T_0$

$P_a = \beta$ for $x_p = T_1$

α = type I risk, β = type II risk, $T_1 > T_0$

Sample size, n:

$$n = \left(1 + \frac{u_p^2}{2} \right) \tilde{\sigma}^2 \left(\frac{u_{1-\alpha} + u_{1-\beta}}{\ln T_1 - \ln T_0} \right)^2$$ (round up to next integer)

where

$\tilde{\sigma}^2$ is a prior estimate of σ^2;

$u_{1-\alpha}$, $u_{1-\beta}$ and u_p are standardized normal deviates.

Minimum sample size: 20 (approximately).

Decision procedure: From a random sample of n active corrective maintenance times $x_1, x_2, ..., x_n$ compute the

sample mean of ln x_i: $\bar{y} = \frac{1}{n} \sum_{i=1}^{n} \ln x_i$

and the sample variance: $s^2 = \frac{1}{n-1} \left[\sum_{i=1}^{n} (\ln x_i)^2 - n\bar{y}^2 \right]$.

Then compute $U = \ln T_0 + u_{1-\alpha} \cdot s \left[\frac{1}{n} + \frac{u_p^2}{2(n-1)} \right]^{\frac{1}{2}}$.

Accept H_0 if $\bar{y} + u_p s \leq U$

Reject H_0 otherwise.

B.5 Test method 5

Test index: ACMT proportion above a specified value.

Assumptions: ACMT is adequately described by a log-normal distribution.

Tested hypothesis: Null hypothesis H_0: $\Pr[X > T] \leq p_0$

Alternative hypothesis H_1: $\Pr[X > T] > p_0$

where

$\Pr[X > T]$ is the probability that the random variable X is greater than the time T.

Probability of acceptance P_a: $P_a = 1 - \alpha$ for $\Pr[X > T] = p_0$

$P_a = \beta$ for $\Pr[X > T] = p_1$

α = type I risk, β = type II risk, $p_1 > p_0$

Sample size, n:

$$n = \left(1 + \frac{k^2}{2}\right) \cdot \left(\frac{u_{1-\alpha} + u_{1-\beta}}{u_{1-p_0} - u_{1-p_1}}\right)^2$$ (round up to next integer),

where

$$k = \frac{u_{1-\alpha} \cdot u_{1-p_1} + u_{1-\beta} \cdot u_{1-p_0}}{u_{1-\alpha} + u_{1-\beta}};$$

$u_{1-\alpha}$, $u_{1-\beta}$ u_{1-p_0}, u_{1-p_0} are standardized normal deviates.

Minimum sample size: 20.

Decision procedure: From a random sample of n active corrective maintenance times $x_1, x_2, ..., x_n$ compute the

sample mean of $\ln x_i$: $$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} \ln x_i$$

and the sample variance $$s^2 = \frac{1}{n-1}\left[\sum_{i=1}^{n}(\ln x_i)^2 - n\bar{y}^2\right]$$

Accept H_0 if $\bar{y} + ks \leq T$;

Reject H_0 otherwise.

B.6 Test method 6

Test index: ACMT proportion above a specified value.

Assumptions: None.

Tested hypotheses: See test method 5.

Probability of acceptance P_a: See test method 5.

Sample size, n, and acceptance number, c: n and c are determined by solving the following equations, n being the smallest integer satisfying the conditions:

$$\sum_{w=0}^{c} \binom{n}{w} p_0^{w} (1 - p_0)^{n-w} \geq 1 - \alpha$$

$$\sum_{w=0}^{c} \binom{n}{w} p_1^{w} (1 - p_1)^{n-w} \leq \beta$$

The equations can be solved:

- — by employing the normal approximation for $0,2 < p_0 < 0,8$;
- — by employing the Poisson approximation for $p_0 < 0,2$ (see Table B.1);
- — directly by use of a computer.

Decision procedure: From a random sample of n active corrective maintenance times $x_1, x_2, ..., x_n$ count the number of such observations exceeding the specified time T.
This number is called r.
Accept H_0 if $r \leq c$.
Reject H_0 if $r > c$.

B.7 Test method 7

Test index: ACMT proportion above a specified value.

Assumptions: None.

Tested hypotheses: See test method 5.

Probability of acceptance P_a: See test method 5.

Sample size: This is a sequential test, i.e. no fixed sample size exists.

Decision procedure: Random samples of active corrective maintenance times $x_1, x_2, ..., x_n$ are taken until a decision to accept or reject can be made. The number of active corrective maintenance times exceeding the specified time T is counted. This number is called d_N for the first N observations. After each observation d_N is compared with the acceptance number a_N and the rejection number r_N (see Table B.2):

$a_N = - b_1 + kN$

$r_N = b_2 + kN$

where

$$b_1 = \frac{\ln \frac{1-\alpha}{\beta}}{\ln \frac{p_1}{p_0} + \ln \frac{1-p_0}{1-p_1}}$$

$$b_2 = \frac{\ln \frac{1-\beta}{\alpha}}{\ln \frac{p_1}{p_0} + \ln \frac{1-p_0}{1-p_1}}$$

$$k = \frac{\ln \frac{1-p_0}{1-p_1}}{\ln \frac{p_1}{p_0} + \ln \frac{1-p_0}{1-p_1}}$$

Accept H_0 if $d_N < a_N$.

Reject H_0 if $d_N > r_N$.

If $r_N > d_N > a_N$ the test is continued with the $(N + 1)$th observation (see Figure B.2). The value of truncation of the test should be:

$$N_E \geq \frac{3b_1}{k}$$

Table B.1 — Sampling plans for specified p_0, p_1, α, β (p_0 < 0,2)

$k = \frac{p_1}{p_0}$	α = 0,05						α = 0,10						α = 0,20					
	β = 0,05		β = 0,10		β = 0,20		β = 0,05		β = 0,10		β = 0,20		β = 0,05		β = 0,10		β = 0,20	
	c	*D*	*c*	*D*	*c*	*D*	*c*	*D*	*c*	*D*	*c*	*D*	*c*	*D*	*c*	*D*	*c*	*D*
1,5	66	54,1	54	43,3	39	30,2	51	43,0	40	33,0	29	23,2	36	31,8	27	23,5	17	14,4
2,0	22	15,7	18	12,4	14	9,25	17	12,8	14	10,3	10	7,02	12	9,91	9	7,29	6	4,73
2,5	13	8,46	10	6,17	8	4,70	10	7,02	8	5,43	6	3,90	7	5,58	5	3,84	3	2,30
3,0	9	5,43	7	3,98	6	3,29	7	4,66	5	3,15	4	2,43	4	3,09	3	2,30	2	1,54
4,0	6	3,29	5	2,51	4	1,97	4	2,43	3	1,75	2	1,10	3	2,30	2	1,54	1	0,824
5,0	4	1,97	3	1,37	3	1,37	3	1,75	2	1,10	2	1,10	2	1,54	1	0,824	1	0,824
10,0	2	0,818	2	0,818	1	0,353	1	0,532	1	0,532	1	0,532	1	0,824	1	0,824	0	0,227

NOTE To find the sample size for *n*, for given p_0, p_1, α and β, divide the appropriate *D* value by p_0 and use the greatest integer less than the quotient.

Example: p_0 = 0,05, p_1 = 0,20, α = 0,10, β = 0,05, and $k = \frac{0,20}{0,05} = 4$. Then $n = \frac{D}{0,05} = \frac{2,43}{0,05} = 48$. The acceptance number is c = 4.

Table B.2 — Test method 7: acceptance and rejection numbers

Observation number N	Acceptance number a_N	Rejection number r_N
3		3
6		3
7		4
12		4
13	0	5
18	0	5
19	1	6
24	1	6
25	2	7
30	2	7
31	3	8
36	3	8
37	4	9
42	4	9
43	5	10
48	5	10
49	6	11
54	6	11
55	7	12
60	7	12
61	8	13
66	8	13
67	9	14
72	9	14
73	10	15
78	10	15
79	11	16
84	11	16
85	12	17
90	12	17
91	13	17
96	13	17
97	14	17
99	14	17
100	16	17

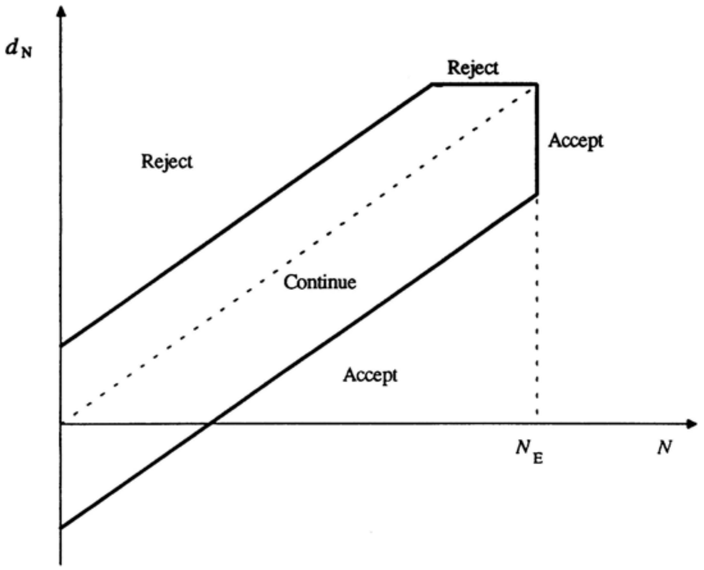

Figure B.1 — Test method 7: sequential test plan

Annex C (informative)
Kolmogorov-Smirnov distribution testing

C.1 Distributions used in maintainability

Most commonly used distribution functions in maintainability are:

— the log-normal distribution;

— the multimodal distribution (in special cases).

In most cases, the log-normal distribution is the best model to use; however, in some cases, the normal distribution might be used as an approximation. The multimodal distribution is sometimes a good representation for data samples with more than one factor of time dependency (failure mechanisms, types of maintenance, etc.).

Procedures used for selecting a suitable distribution model are outside the scope of this annex. In such a case, the reader should refer to statistical textbooks.

C.2 Kolmogorov-Smirnov test for distribution testing

The Kolmogorov-Smirnov or *d*-test is accomplished by plotting the hypothesized theoretical distribution (e.g. log-normal), using, as appropriate, the observed data for parameter estimation (e.g. mean and standard deviation). About this theoretical distribution, boundaries are constructed which are plus or minus *d* probability units. Table C.1 provides a limited set of the *d* values which are selected, based on data sample size and the level of significance (α) for which the test is to be conducted. The observed data distribution is next plotted, If the observed function passes outside the boundaries at any point, then the hypothesized theoretical distribution is not consistent with the data. Conversely, if the observed function always remains inside the boundaries, the hypothesis concerning the underlying distribution cannot be rejected.

Table C.1 — Critical values of *d*

Sample size	Level of significance (α)			
	0,15	0,10	0,05	0,01
5	0,474	0,510	0,565	0,669
10	0,342	0,368	0,410	0,490
15	0,283	0,304	0,338	0,404
20	0,246	0,264	0,294	0,356
30	0,20	0,22	0,24	0,29
40	0,18	0,19	0,21	0,25
50	0,16	0,17	0,19	0,23
over 50	$\frac{1,14}{\sqrt{n}}$	$\frac{1,22}{\sqrt{n}}$	$\frac{1,36}{\sqrt{n}}$	$\frac{1,63}{\sqrt{n}}$

NOTE The *d* values shown are based on a complete specification of the hypothesized distribution. If sample data are used to estimate the parameter(s), multiply the table *d*-value by 0,80 for testing the exponential and by 0,67 for testing the normal distribution.

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List of references

See national foreword.

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