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NORME INTERNATIONALE

Mathematical expressions for reliability, availability, maintainability and maintenance support terms

Expressions mathématiques pour les termes de fiabilité, de disponibilité, de maintenabilité et de logistique de maintenance

IEC 61703:2016-08(en-fr)

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MATHEMATICAL EXPRESSIONS FOR RELIABILITY, AVAILABILITY, MAINTAINABILITY AND MAINTENANCE SUPPORT TERMS

FOREWORD

International Standard IEC 61703 has been prepared by IEC technical committee 56: Dependability.

This second edition cancels and replaces the first edition published in 2001. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) standard made as self containing as possible;
b) item split between individual items and systems;
c) generalization of the dependability concepts for systems made of several components;
   – introduction of the conditional failure intensity (Vesely failure rate);
   – introduction of the state-transition and the Markovian models;

– generalization of the availability to production availability;

d) introduction of curves to illustrate the various concepts.

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

FDIS	Report on voting
56/1682/FDIS	56/1693/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.

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

This International Standard is to be used in conjunction with IEC 60050-192:2015.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,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

INTRODUCTION

IEC 60050-192 provides definitions for dependability and its influencing factors, reliability, availability, maintainability and maintenance support, together with definitions of other related terms commonly used in this field. Some of these terms are measures of specific dependability characteristics, which can be expressed mathematically.

It is important for the users to understand the mathematical meaning of those expressions and how they are established. This is the purpose of the present International Standard which, used in conjunction with IEC 60050-192, provides practical guidance essential for the quantification of those measures. For those requiring further information, for example on detailed statistical methods, reference should be made to the IEC 60605 series [23][1].

Annex A provides a diagrammatic explanation of the relationships between some basic dependability terms, related random variables, probabilistic descriptors and modifiers.

Annex B provides a summary of measures related to time to failure.

Annex C compares some dependability measures for continuously operating items.

The bibliography gives references for the mathematical basis of this standard, in particular, the mathematical material is based on references [2], [6], [8], [9], [13], [14] and [18]; the renewal theory (renewal and alternating renewal processes) can be found in [6], [8], [9], [10], [11], [13], [15], and [17]; and more advanced treatment of renewal theory can be found in references [1], [3], [12], [16], [19] and [20]. More information on the theory and applications of Markov processes can be found in references [3], [9], [10], [15], [16], [17] and [19].

1 Numbers in brackets refer to the Bibliography.

MATHEMATICAL EXPRESSIONS FOR RELIABILITY, AVAILABILITY, MAINTAINABILITY AND MAINTENANCE SUPPORT TERMS

1 Scope

This International Standard provides mathematical expressions for selected reliability, availability, maintainability and maintenance support measures defined in IEC 60050-192:2015. In addition, it introduces some terms not covered in IEC 60050-192:2015. They are related to aspects of the system of item classes (see hereafter).

According to IEC 60050-192:2015, dependability [192-01-22] is the ability of an item to perform as and when required and an item [192-01-01] can be an individual part, component, device, functional unit, equipment, subsystem, or system.

To account for mathematical constraints, this standard splits the items between the individual items considered as a whole (e.g. individual components) and the systems made of several individual items. It provides general considerations for the mathematical expressions for systems as well as individual items but the individual items which are easier to model are analysed in more detail with regards to their repair aspects.

The following item classes are considered separately:

- Systems;
- Individual items:
  - non-repairable [192-01-12];
  - repairable [192-01-11]:
    - i) with zero (or negligible) time to restoration;
    - ii) with non-zero time to restoration.

In order to explain the dependability concepts which can be difficult to understand, keep the standard self-contained and the mathematical formulae as simple as possible, the following basic mathematical models are used in this standard to quantify dependability measures:

- Systems:
  - state-transition models;
  - Markovian models.
- Individual items:
  - random variable (time to failure) for non-repairable items;
  - simple (ordinary) renewal process for repairable items with zero time to restoration;
  - simple (ordinary) alternating renewal process for repairable items with non-zero time to restoration.

The application of each dependability measure is illustrated by means of simple examples.

This standard is mainly applicable to hardware dependability, but many terms and their definitions may be applied to items containing software.

2 Normative references

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

IEC 60050-192:2015, *International electrotechnical vocabulary – Part 192: Dependability* (available at http://www.electropedia.org)

ISO 3534-1:2006, *Statistics – Vocabulary and symbols – Part 1: General statistical terms and terms used in probability*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-192:2015, ISO 3534-1 and the following apply.

NOTE To facilitate the location of the full definition, the IEC 60050-192 reference for each term is shown [in square brackets] immediately following each term, for example:

mean time to restoration **[192-07-23]**

The terms and definitions given in Clause 3, which do not appear in IEC 60050-192, are used in order to facilitate the presentation of mathematical expressions of some IEC 60050-192 terms. Some terms have been taken from IEC 60050-192 and modified for the needs of this standard.

3.1
instantaneous restoration intensity
restoration intensity
restoration frequency
$\nu(t)$
limit, if it exists, of the quotient of the mean number of restorations [192-06-23] of a repairable item [192-01-11] within time interval $[t, t + \Delta t]$, and Δt, when Δt tends to zero, given that the item is as good as new at $t = 0$

$$\nu(t) = \lim_{\Delta t \to 0+} \frac{E\left[N_{\mathrm{R}}(t+\Delta t) - N_{\mathrm{R}}(t) \mid \text{as good as new at } t=0\right]}{\Delta t}$$

where

$N_{\mathrm{R}}(t)$ is the number of restorations in the time interval $[0, t]$;

E denotes the expectation.

Note 1 to entry: The difference between the restoration intensity and the repair rate comes from the conditions: the item is as good as new at time $t = 0$ for the restoration intensity and for the repair rate the repair starts at time $t = 0$. From a mathematical point of view, the restoration intensity is similar to the unconditional failure intensity (see 3.8).

Note 2 to entry: The unit of measurement of instantaneous restoration intensity is the unit of time to the power-1.

3.2
instantaneous repair rate
repair rate
$\mu(t)$
limit, if it exists, of the quotient of the conditional probability that the repair is completed within time interval $[t, t + \Delta t]$ and Δt, when Δt tends to zero, given that the repair started at $t = 0$ and had not been completed before time t

Note 1 to entry: The difference between the restoration intensity and the repair rate comes from the conditions: the item is as good as new at time $t = 0$ for the restoration intensity and for the repair rate the repair starts at time $t = 0$. From a mathematical point of view, the repair rate is similar to the failure rate (see 3.6).

[SOURCE: IEC 60050-192:2015, 192-07-20, modified — Note 1 to entry has been replaced and Note 2 to entry deleted]

3.3
mean time between failures
METBF
expectation of the time which elapses between successive failures

Note 1 to entry: The concept of mean time between failures has been omitted from IEC 60050-192. It was defined in IEC 60050-191 as “the expectation of time between failures”. The definition has been modified to explain the acronym METBF (mean elapsed time between failures) which is used in this standard to avoid any confusion between the mean time between failure (METBF) and the mean operating time between failures (MTBF or MOTBF).

[SOURCE: IEC 60050-191:1990, 191-12-08, modified — acronym and Note 1 to entry added]

3.4
up-time distribution function
function giving, for every value of t, the probability that an up-time will be less than, or equal to, t

Note 1 to entry: If the up-time is (strictly) positive and a continuous random variable, then $F_U(0) = 0$ and

$$F_U(t) = 1 - \exp\left(-\int_0^t \lambda_U(x)\,dx\right)$$

where

$\lambda_U(t)$ is the instantaneous up-time hazard rate function.

Note 2 to entry: The up-time distribution function is the general up-time distribution valid for both COI (continuously operating item) and IOI (intermittently operating item). For COIs, $F_U(t) = F(t)$

Note 3 to entry: If the up time is exponentially distributed, then

$$F_U(t) = 1 - \exp(-t/\text{MUT})$$

where MUT is the mean up-time.

In this case, the reciprocal of MUT is denoted by λ_U and $\lambda_U = 1/\text{MUT}$

3.5
instantaneous up-time hazard rate function
up-time hazard rate function
$\lambda_U(t)$
limit, if it exists, of the quotient of the conditional probability that the up-time will end within time interval $[t, t + \Delta t]$ and Δt, when Δt tends to zero, given that the up-time started at $t = 0$ and had not been finished before time t

Note 1 to entry: The instantaneous up-time hazard rate function is expressed by the formula:

$$\lambda_U(t) = \lim_{\Delta t \to 0+} \frac{1}{\Delta t} \frac{F_U(t + \Delta t) - F_U(t)}{1 - F_U(t)} = \frac{f_U(t)}{1 - F_U(t)}$$

where $F_U(t)$ is the up-time distribution function and $f_U(t)$ is the probability density function of the up-time.

Note 2 to entry: $\lambda_U(t)$ is the general hazard rate for the up times valid for both COI and IOI. For COIs, $\lambda_U(t) = \lambda(t)$ (see 3.6).

Note 3 to entry: If the up time is exponentially distributed, then the instantaneous up-time hazard rate function is constant in time and is denoted by λ_U.

Note 4 to entry: The unit of measurement of instantaneous up-time hazard rate function is the unit of time to the power −1.

3.6
instantaneous failure rate
failure rate
$\lambda(t)$
limit, if it exists, of the quotient of the conditional probability that the failure of an item occurs within time interval $[t, t + \Delta t]$, by Δt, when Δt tends to zero, given that failure has not occurred within time interval $[0, t]$

Note 1 to entry: The instantaneous failure rate is expressed by the formula:

$$\lambda\,(t) = \lim_{\Delta t \to 0+} \frac{1}{\Delta t} \frac{F(t+\Delta t) - F(t)}{R(t)} = \frac{f(t)}{R(t)}$$

where $F(t)$ and $f(t)$ are, respectively, the distribution function and the probability density at the failure instant, and where $R(t)$ is the reliability function, related to the reliability $R(t_1, t_2)$ by $R(t) = R(0, t)$.

Note 2 to entry: The restriction to non-repairable items in the definition provided by IEC 60050-192 can be removed to generalize this definition for any kind of items i.e. systems or individual items, repairable or not.

Note 3 to entry: The instantaneous failure rate is the up-time hazard rate for COIs. In this case, $\lambda(t) = \lambda_U(t)$ (see 3.5).

Note 4 to entry: When $\Delta t \to 0+$, the failure rate is the conditional probability per unit of time that the item fails between t and $t + \Delta t$, given it is in up state all over the time interval $[0, t]$. It is usually assumed that the item is as good as new at time 0.

Note 5 to entry: The instantaneous failure rate may be also expressed by the formula:

$$\lambda(t) = \lim_{\Delta t \to 0+} \frac{E\left[N(t+\Delta t) - N(t) \,|\, \text{up state over } [0, \text{t}]\right]}{\Delta t}$$

where $N(t)$ is the number of failures in the time interval $[0, t]$, where E denotes the expectation.

This form of the definitions allows comparisons of the failure rate to the conditional failure intensity and to the unconditional failure intensity.

[SOURCE: IEC 60050-192:2015, 192-05-06, modified — generalized to systems with repairable components and Notes to entry added]

3.7
conditional failure intensity
Vesely failure rate
$\lambda_V(t)$
limit, if it exists, of the quotient of the mean number of failures of a repairable item within time interval $[t, t + \Delta t]$, by Δt, when Δt tends to zero, given that the item is in up state at time t and as good as new at time 0

Note 1 to entry: The instantaneous failure intensity is expressed by the formula:

$$\lambda_V\,(t) = \lim_{\Delta t \to 0+} \frac{E\left[N(t+\Delta t) - N(t) \,|\, \text{up state at } t \text{ and as good as new at time 0}\right]}{\Delta t}$$

where $N(t)$ is the number of failures in the time interval $[0, t]$, where E denotes the expectation.

Note 2 to entry: When $\Delta t \to 0+$, the conditional failure intensity is the probability per unit of time that the item fails between t and $t + \mathrm{d}t$, given it is in up state at time t and as good as new at time 0. In particular cases (quick restoration of failures), it provides good approximations of the failure rate. This parameter introduced in 1970 by W. E. Vesely [26] is also called Vesely failure rate.

Note 3 to entry: According to the definitions, $\lambda_V(t)$ and $z(t)$ are linked by the formula: $\lambda_V(t) = z(t)/A(t)$. where $A(t)$ is the item instantaneous availability at time t.

3.8
unconditional failure intensity
instantaneous failure intensity
failure intensity
failure frequency
$z(t)$
limit, if it exists, of the quotient of the mean number of failures of a repairable item within time interval $[t, t + \Delta t]$, by Δt, when Δt tends to zero, given that the item is as good as new at time $t = 0$

Note 1 to entry: The instantaneous failure intensity is expressed by the formula:

$$z(t) = \lim_{\Delta t \to 0+} \frac{E\left[N(t+\Delta t) - N(t) \mid \text{as good as new at } t = 0\right]}{\Delta t}$$

where $N(t)$ is the number of failures in the time interval $[0, t]$, where E denotes the expectation and where the implicit condition that the item is as good as new at time $t = 0$ has been added.

Note 2 to entry: The unconditional failure intensity is the failure intensity as defined in IEC 60050-192:2015 [192-05-08]. It is also sometimes named ROCOF (rate of occurrence of failure).

Note 3 to entry: When $\Delta t \to 0+$, the unconditional failure intensity is the probability per unit of time that the item fails between t and $t + dt$ given that the item is in up state at time $t = 0$. Here the item may be in any state at time t and this is why the adjective unconditional is used.

Note 4 to entry: According to the definitions, $\lambda_V(t)$ and $z(t)$ are linked by the formula: $z(t) = A(t) \cdot \lambda_V(t)$ where $A(t)$ is the item instantaneous availability at time t.

[SOURCE: IEC 60050-192:2015, 192-05-08, modified — synonyms have been added and the entry has been revised]

3.9
continuously operating item
COI
item for which operating time [192-02-05] is equal to its enabled time [192-02-17]

3.10
intermittently operating item
IOI
item for which operating time [192-02-05] is less than its enabled time [192-02-17]

Note 1 to entry: In this case, the enabled time of the item is made of the sum of the times spent in the operating [192-02-04], idle [192-02-14] and standby [192-02-10] states.

4 Glossary of symbols and abbreviations

4.1 General

The symbols and abbreviations given in Clause 4 are widely used and recommended, however, they are not mandatory. For consistency of presentation, the notation in this document may differ from that used in a referenced document.

4.2 Acronyms used in this standard

Acronym/abbreviation	Meaning
COI	Continuously operating item
IOI	Intermittently operating item
MACMT	Mean active corrective maintenance time, i.e. the expectation of the active corrective maintenance time