

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

ICS 21.020

National foreword

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**Mathematical expressions for reliability, availability,
maintainability and maintenance support terms**
(IEC 61703:2001)

Expressions mathématiques pour
les termes de fiabilité, de disponibilité,
de maintenabilité et de logistique
de maintenance
(CEI 61703:2001)

Mathematische Ausdrücke für Begriffe
der Funktionsfähigkeit, Instandhaltbarkeit
und Verfügbarkeit
(IEC 61703:2001)

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Foreword

The text of document 56/747/FDIS, future edition 1 of IEC 61703, prepared by IEC TC 56, Dependability, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61703 on 2001-12-04.

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at national level by publication of an identical
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with the EN have to be withdrawn (dow) 2004-12-01

Annexes designated "normative" are part of the body of the standard.

Annexes designated "informative" are given for information only.

In this standard, annex ZA is normative and annexes A, B, C and D are informative.

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61703:2001 was approved by CENELEC as a European Standard without any modification.

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

1 Scope

This International Standard provides mathematical expressions for reliability, availability, maintainability and maintenance support measures defined in IEC 60050-191. The following classes of items are considered separately in this standard:

- non-repaired items;
- repaired items with zero time to restoration;
- repaired items with non-zero time to restoration.

In order to keep the mathematical formulae as simple as possible, the following basic mathematical models are used to quantify dependability measures:

- random variable (time to failure) for non-repaired items;
- simple (ordinary) renewal process for repaired items with zero time to restoration;
- simple (ordinary) alternating renewal process for repaired items with non-zero time to restoration.

To facilitate location of the full definition, the IEC 60050-191 reference for each term is shown (in parenthesis) immediately following each term, for example:

mean time to restoration [191-13-08]

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

NOTE This standard is mainly applicable to hardware dependability, but many terms and their definitions may be applied to items containing software. Some of the software dependability aspects are explained in annex D.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

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

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

3 Definitions

For the purpose of this International Standard, the terms and definitions of IEC 60050-191 and ISO 3534-1 apply. In addition, the following terms and definitions are used.

3.1

instantaneous restoration intensity $v(t)$

limit, if it exists, of the quotient of the mean number of restorations of a repaired item in the time interval $(t, t + \Delta t)$ and the duration of this interval, Δt , when the duration of the time interval tends to zero

NOTE The instantaneous restoration intensity is expressed by the formula as

$$v(t) = \lim_{\Delta t \rightarrow 0+} \frac{E[N_R(t + \Delta t) - N_R(t)]}{\Delta t}$$

where

$N_R(t)$ is the number of restorations in the time interval $(0, t)$;

E denotes the expectation.

3.2

asymptotic failure intensity $z(\infty)$

for modelling purposes, limit, if it exists, of the instantaneous failure intensity $z(t)$, when time t tends to infinity

3.3

up-time distribution function $F_U(t)$

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

3.4

complement to the up-time distribution function $R_U(t)$

function giving, for every value of t , the probability that an up time will be greater than t

For convenience, this function is referred to as the **up-time survival function** in this standard.

NOTE 1 $R_U(t) = 1 - F_U(t)$.

NOTE 2 If the up time is exponentially distributed, then

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

where MUT is the mean up time.

In this case, the reciprocal of MUT is denoted by λ_U :

$$\lambda_U = 1/\text{MUT}$$

4 Glossary of symbols and abbreviations

NOTE The symbols given below are widely used and recommended but are not mandatory.

4.1 Non-repaired items

COI	Continuously operating item
IOI	Intermittently operating item
MTTF	Mean time to failure
$\hat{\text{MTTF}}$	Point estimate of the mean time to failure
$R(t)$	Reliability function, i.e. the probability of survival until time t : $R(t) = R(t_1, t_2)$ for $t_1 = 0$ and $t_2 = t$
$\hat{R}(t)$	Point estimate of the reliability function at time t
$R(t_1, t_2)$	Reliability for the time interval (t_1, t_2)
$R(t, t+x t)$	Conditional reliability for the time interval $(t, t+x)$, assuming that the item survived to time t
TTF_i	Observed time to failure of item i
$f(t)$	Probability density function of the (operating) time to failure
$\hat{f}(t)$	Point estimate of the probability density function of the (operating) time to failure at time t
n	Number of (non-repaired) items in the population that are operational at the instant of time $t = 0$
$n_S(t)$	Number of (non-repaired) items that are still operational at the instant of time t ($n_S(0) = n$)
$n_S(t) - n_S(t + \Delta t)$	Number of items that fail in the time interval $(t, t + \Delta t)$
λ	Constant failure rate, i.e. the reciprocal of the mean time to failure (MTTF) when the times to failure are exponentially distributed
$\hat{\lambda}$	Point estimate of the constant failure rate
$\lambda(t)$	Instantaneous failure rate
$\hat{\lambda}(t)$	Point estimate of the instantaneous failure rate at time t
$\bar{\lambda}(t_1, t_2)$	Mean failure rate for the time interval (t_1, t_2)

4.2 Repaired items with zero time to restoration

COI	Continuously operating item
IOI	Intermittently operating item
MTBF	Mean operating time between failures
MTTF	Mean time to failure
$\hat{MTTF}$	Point estimate of the mean time to failure
MUT	Mean up time
$N(t)$	Number of failures in the time interval $(0, t)$
$R(t)$	Reliability function, i.e. the probability of survival until time t : $R(t) = R(t_1, t_2)$ for $t_1 = 0$ and $t_2 = t$
$R_U(t)$	Up-time survival function, i.e. the distribution function of the up times is $1 - R_U(t)$
$R(t_1, t_2)$	Reliability for the time interval (t_1, t_2)
$\hat{R}(t_1, t_2)$	Point estimate of the reliability for the time interval (t_1, t_2)
$Z(t)$	Expected number of failures in the time interval $(0, t)$ $Z(t) = E[N(t)]$, where E denotes the expectation
$f(t)$	Probability density function of the (operating) times to failure
$f_U(t)$	Probability density function of the up times NOTE For COIs, $f_U(t) = f(t)$.
$h_{CTTF}^{(n)}(t)$	Probability density function of calendar time to the n th failure, $n \geq 1$
k_F	Number of failures during a given period of observation
n	Number of items in the population
$n_F(t, t + \Delta t)$	Number of failures observed in the time interval $(t, t + \Delta t)$
$n_F(t_1, t_2)$	Number of failures observed in the time interval (t_1, t_2)
$n_S(t_1, t_2)$	Number of items that were operational at the instant of time t_1 and operated without failure during the time interval (t_1, t_2)
$z(t)$	Instantaneous failure intensity
$z(\infty)$	Asymptotic failure intensity
$\hat{z}(t)$	Point estimate of the instantaneous failure intensity at time t
$\bar{z}(t_1, t_2)$	Mean failure intensity for the time interval (t_1, t_2)
$\hat{\bar{z}}(t_1, t_2)$	Point estimate of the mean failure intensity for the time interval (t_1, t_2)
λ	Constant failure rate, i.e. the reciprocal of the mean time to failure (MTTF) when the times to failure are exponentially distributed
λ_U	Constant rate of transition from an up state to a down state, i.e. the reciprocal of the mean up time (MUT) when the up time is exponentially distributed

4.3 Repaired items with non-zero time to restoration

A	Asymptotic availability
$A(t)$	Instantaneous availability (availability function), i.e. the probability of the item being in an up state at the instant of time t
$\bar{A}(t_1, t_2)$	Mean availability for the time interval (t_1, t_2)
$\hat{A}(t_1, t_2)$	Point estimate of the mean availability for the time interval (t_1, t_2)
COI	Continuously operating item
$G_R(t)$	Distribution function of the times to restoration
IOI	Intermittently operating item
$M(t)$	Maintainability function, i.e. the probability of completing active maintenance action within time t : $M(t) = M(t_1, t_2)$ for $t_1 = 0$ and $t_2 = t$
$M(t_1, t_2)$	Maintainability for the time interval (t_1, t_2)
$N(t)$	Number of failures occurring in the time interval $(0, t)$
$N_R(t)$	Number of restorations occurring in the time interval $(0, t)$
$R(t)$	Reliability function, i.e. the probability of survival until time t $R(t) = R(t_1, t_2)$ for $t_1 = 0$ and $t_2 = t$
$R_U(t)$	Up-time survival function, i.e. the distribution function of the up times is $1 - R_U(t)$
$R(t_1, t_2)$	Reliability for the time interval (t_1, t_2)
MACMT	Mean active corrective maintenance time, i.e. the expectation of the active corrective maintenance time
$\hat{\text{MACMT}}$	Point estimate of the mean active corrective maintenance time
MAD	Mean administrative delay
$\hat{\text{MAD}}$	Point estimate of the mean administrative delay
MADT	Mean accumulated down time
$\hat{\text{MADT}}$	Point estimate of the mean accumulated down time
MAMT	Mean active maintenance time, i.e. the expectation of the active maintenance time
MCMT	Mean corrective maintenance time, i.e. the expectation of the corrective maintenance time
MDT	Mean down time
$\hat{\text{MDT}}$	Point estimate of the mean down time
MLD	Mean logistic delay
$\hat{\text{MLD}}$	Point estimate of the mean logistic delay
MRT	Mean repair time
$\hat{\text{MRT}}$	Point estimate of the mean repair time
MTBF	Mean operating time between failures
MTD	Mean technical delay, i.e. the expectation of the technical delay

MTTF	Mean time to failure
$\hat{MTTF}$	Point estimate of the mean time to failure
MTTR	Mean time to restoration
$\hat{MTTR}$	Point estimate of the mean time to restoration
MUFT	Mean undetected fault time, i.e. the expectation of the undetected fault time
MUT	Mean up time
$\hat{MUT}$	Point estimate of the mean up time
U	Asymptotic unavailability
$U(t)$	Instantaneous unavailability (unavailability function)
$\bar{U}(t_1, t_2)$	Mean unavailability for the time interval (t_1, t_2)
$\hat{\bar{U}}(t_1, t_2)$	Point estimate of the mean unavailability for the time interval (t_1, t_2)
$Z(t)$	Expected number of failures in the time interval $(0, t)$ $Z(t) = E[N(t)]$, where E denotes the expectation
$f(t)$	Probability density function of the (operating) times to failure
$f_U(t)$	Probability density function of the up times
$f_{U+R}(t)$	Probability density function of the sum of the up times and the corresponding times to restoration
$g_{ACM}(t)$	Probability density function of the active corrective maintenance times
$g_{AD}(t)$	Probability density function of the administrative delays
$g_{AM}(t)$	Probability density function of the active maintenance times
$g_D(t)$	Probability density function of the down times
$g_{LD}(t)$	Probability density function of the logistic delays
$g_R(t)$	Probability density function of the times to restoration
$g_{Rep}(t)$	Probability density function of the repair times
$h_{CTTF}^{(n)}(t)$	Probability density function of calendar time to the n th failure, $n \geq 1$
k_{ACM}	Number of active corrective maintenance actions during a given period of observation
k_{AD}	Number of administrative delays during a given period of observation
k_D	Number of down times during a given period of observation
k_F	Number of failures during a given period of observation
k_{LD}	Number of logistic delays during a given period of observation
k_O	Number of failures while operating during a given period of observation
k_R	Number of times to restoration during a given period of observation
k_{Rep}	Number of repair times during a given period of observation
k_U	Number of up times during a given period of observation
n	Number of items in the population

$n_D\{t\}$	Number of items that are in a down state at the instant of time t
$n_F(t, t + \Delta t)$	Number of failures observed during the time interval $(t, t + \Delta t)$, where the time scale includes both up and down times
$n_F(t, t_2)$	Number of failures observed during the time interval (t, t_2) , where the time scale includes both up and down times
$n_S(t_1, t_2)$	Number of items that were operational at the instant of time t_1 and operated without failure in the time interval (t_1, t_2)
$n_U\{t\}$	Number of items that are in an up state at the instant of time t
$v(t)$	Instantaneous restoration intensity
$z(t)$	Instantaneous failure intensity
$z(\infty)$	Asymptotic failure intensity
$\hat{z}(t)$	Point estimate of the instantaneous failure intensity at time t
$\bar{z}(t_1, t_2)$	Mean failure intensity for the time interval (t_1, t_2)
$\hat{\bar{z}}(t_1, t_2)$	Point estimate of the mean failure intensity for the time interval (t_1, t_2)
λ	Constant failure rate, i.e. the reciprocal of mean time to failure (MTTF) when time to failure is exponentially distributed
λ_U	Constant rate of transition from an up state to a down state, i.e. the reciprocal of the mean up time (MUT) when up times are exponentially distributed
μ	Constant repair rate, i.e. the reciprocal of the mean corrective maintenance time (MCMT) when the corrective maintenance times are exponentially distributed
$\mu(t)$	Instantaneous repair rate
$\bar{\mu}(t_1, t_2)$	Mean repair rate for the time interval (t_1, t_2)
μ_{ACM}	Reciprocal of the mean active corrective maintenance time (MACMT) when the active corrective maintenance times are exponentially distributed
μ_{AD}	Reciprocal of the mean administrative delay (MAD) when the administrative delays are exponentially distributed
μ_{AM}	Reciprocal of the mean active maintenance time (MAMT) when the active maintenance times are exponentially distributed
μ_D	Reciprocal of the mean down time (MDT) when the down times are exponentially distributed
μ_{LD}	Reciprocal of the mean logistic delay (MLD) when the logistic delays are exponentially distributed
μ_R	Constant rate at which the item is restored to service (constant restoration rate), i.e. the reciprocal of the mean time to restoration (MTTR) when the times to restoration are exponentially distributed
μ_{Rep}	Reciprocal of the mean repair time (MRT) when the repair times are exponentially distributed

5 Assumptions

5.1 General remarks

In order to derive correct mathematical expressions for the measures defined in IEC 60050-191, the distinction needs to be made between repaired items [191-01-02] and non-repaired items [191-01-03]. The following classes of items are considered separately in this standard:

- non-repaired items;
- repaired items with zero time to restoration;
- repaired items with non-zero time to restoration.

In order to keep the mathematical formulae as simple as possible, the following basic mathematical models are used to quantify dependability measures:

- random variable (time to failure) for non-repaired items;
- simple (ordinary) renewal process for repaired items with zero time to restoration;
- simple (ordinary) alternating renewal process for repaired items with non-zero time to restoration.

The simplest mathematical model for the reliability of a non-repaired item is a random variable – the time to failure of the item [191-10-02]. One of the widely used reliability measures of non-repaired items is the instantaneous failure rate $\lambda(t)$ [191-12-02], also referred to as the hazard rate function. It is derived from the distribution function of the time to failure. The expression $\lambda(t)\Delta t$ is the conditional probability of failure of an item during the time interval $(t, t + \Delta t)$ given that the item has not failed during the interval $(0, t)$.

For repaired items, the basic model is a simple renewal process, when the time to restoration of the item may be neglected, or a simple alternating renewal process when the time to restoration of the item is non-zero. In the latter case, the item alternates between an up state and a down state, and a widely used measure of reliability of the item is the failure intensity, which is equal to the renewal density.

The failure intensity [191-12-04] is a measure derived from the expected value of the cumulative number of failures $E[N(t)]$ of a repaired item occurring during the time interval $(0, t)$. The expression $z(t)\Delta t$ is the probability of failure of the item during the time interval $(t, t + \Delta t)$.

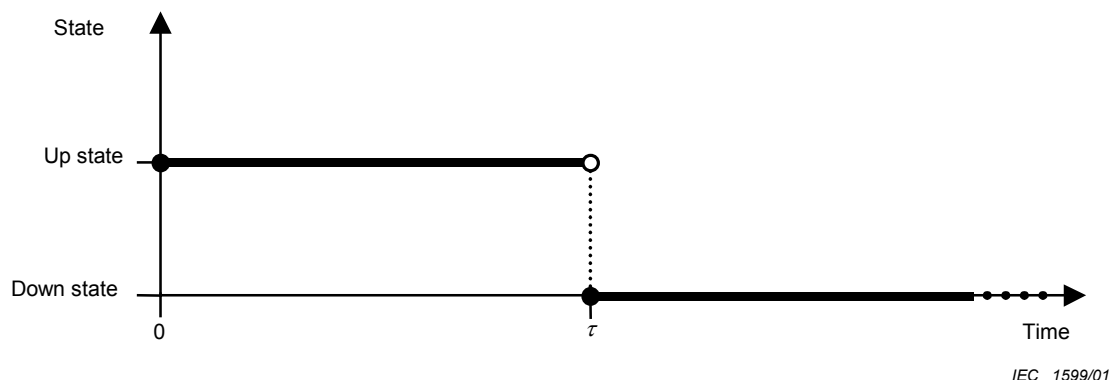
To avoid improper use of these mathematical expressions, specific assumptions are detailed in 5.2 and 5.3.

5.2 Assumptions for non-repaired items

- a) At any instant of time, the non-repaired item may be either in an up state or in a down state (see figure 1).
- b) Unless otherwise stated, when the item is in the up state, it is considered to be continuously operating.

NOTE The mathematical expressions given may not be true for IOIs.

- c) At time $t = 0$, the item is in an operating state and is as good as new. Latent faults are not considered.
- d) Preventive maintenance or other planned actions that render the item incapable of performing a required function are not considered.
- e) The time to failure is a positive and continuous random variable with finite expectation.



Key

τ Time to failure

Figure 1 – Sample realization of a non-repaired item

5.3 Assumptions for repaired items

- a) At any instant of time, the repaired item may be either in an up state or in a down state (see figures 2 and 3).
- b) At time $t = 0$, the item is in an up state and is as good as new. Latent faults are not considered.
- c) Unless otherwise stated, when the item is in the up state, it is considered to be continuously operating.
- d) Consecutive up times of the item are statistically independent, identically distributed, positive and continuous random variables with finite expectations.
- e) Consecutive down times of the item are statistically independent, identically distributed and non-negative random variables with finite expectations. In the case of non-zero down-time duration, the random variables are continuous with a common probability density function.
- f) The up times are statistically independent of the down times.
- g) Preventive maintenance or other planned actions that render the item incapable of performing a required function are not considered.

In other words,

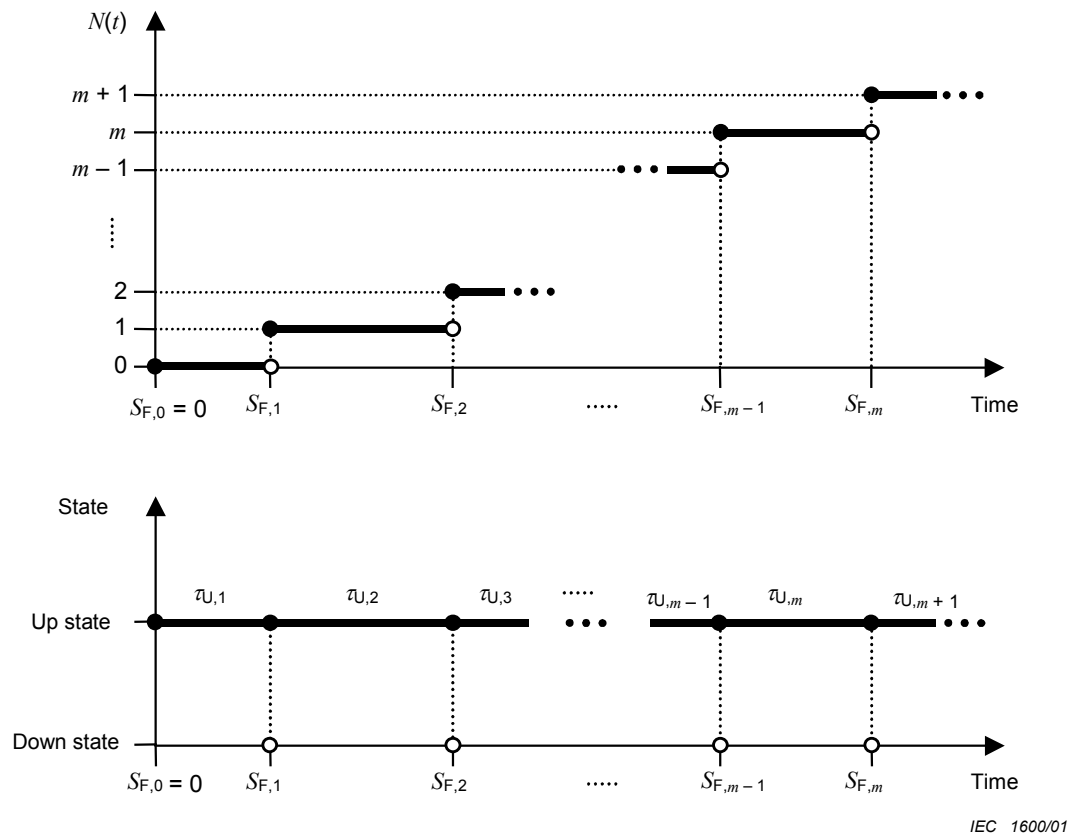
- any transition from an up state to a down state is a failure;
- any transition from a down state to an up state is a restoration;
- any down state is a fault and, in consequence, the down time is equal to the time to restoration;
- after each restoration the item is as good as new.

In this standard, continuously operating items are marked by the abbreviation COI. In this case, the up state is equivalent to the operating state, and any up time is equal to the operating time.

The expressions for reliability measures of continuously operating repaired items may not be true for IOIs (see figure 4).

NOTE 1 Models assuming zero time to restoration are used when either the up time of the item is the only time of interest in assessing the performance of the item, or the time to restoration is so short that it is negligible.

NOTE 2 All mathematical expressions for the reliability measures relating to the time to failure of a non-repaired item may also be applied to each time to failure of a continuously operating repaired item.



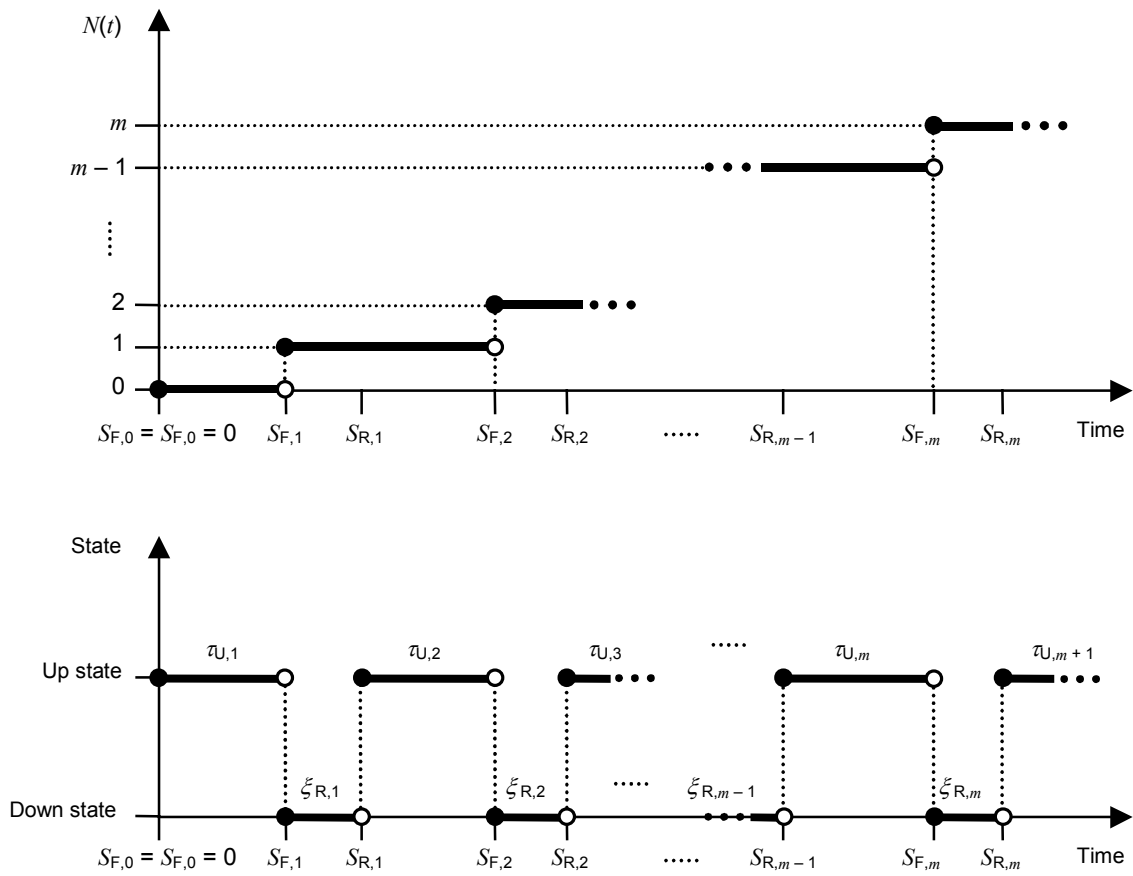
Key

$N(t)$ Number of failures during the time interval $(0, t)$

$S_{F,1}, S_{F,2}, S_{F,3} \dots$ Consecutive instants of failure

$\tau_{U,1}, \tau_{U,2}, \tau_{U,3} \dots$ Consecutive up times

Figure 2 – Sample realization of a repaired item with zero time to restoration



IEC 1601/01

- Key**
- $N(t)$ Number of failures during the time interval $(0, t)$
 - $S_{F,1}, S_{F,2}, S_{F,3} \dots$ Consecutive instants of failure
 - $S_{R,1}, S_{R,2}, S_{R,3} \dots$ Consecutive instants of restoration
 - $\tau_{U,1}, \tau_{U,2}, \tau_{U,3} \dots$ Consecutive up times
 - $\zeta_{R,1}, \zeta_{R,2}, \zeta_{R,3} \dots$ Consecutive times to restoration

Figure 3 – Sample realization of a repaired item with non-zero time to restoration