

# INTERNATIONAL STANDARD

## NORME INTERNATIONALE

**Weibull analysis iTeh STANDARD PREVIEW**  
**Analyse de Weibull (standards.iteh.ai)**

[IEC 61649:2008](#)

<https://standards.iteh.ai/catalog/standards/sist/8f778a3f-f6e1-47e8-b78a-949f476bde67/iec-61649-2008>



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## INTERNATIONAL ELECTROTECHNICAL COMMISSION

## WEIBULL ANALYSIS

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International Standard IEC 61649 has been prepared by IEC technical committee 56: Dependability.

This second edition cancels and replaces the first edition, published in 1997, and constitutes a technical revision.

The main changes with respect to the previous edition are as follows:

- the title has been shortened and simplified to read "Weibull analysis";
- provision of methods for both analytical and graphical solutions have been added.

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

FDIS	Report on voting
56/1269/FDIS	56/1281/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.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site 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- withdrawn,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.

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## INTRODUCTION

The Weibull distribution is used to model data regardless of whether the failure rate is increasing, decreasing or constant. The Weibull distribution is flexible and adaptable to a wide range of data. The time to failure, cycles to failure, mileage to failure, mechanical stress or similar continuous parameters need to be recorded for all items. A life distribution can be modelled even if not all the items have failed.

Guidance is given on how to perform an analysis using a spreadsheet program. Guidance is also given on how to analyse different failure modes separately and identify a possible weak population. Using the three-parameter Weibull distribution can give information on time to first failure or minimum endurance in the sample.

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# WEIBULL ANALYSIS

## 1 Scope

This International Standard provides methods for analysing data from a Weibull distribution using continuous parameters such as time to failure, cycles to failure, mechanical stress, etc.

This standard is applicable whenever data on strength parameters, e.g. times to failure, cycles, stress, etc. are available for a random sample of items operating under test conditions or in-service, for the purpose of estimating measures of reliability performance of the population from which these items were drawn.

This standard is applicable when the data being analysed are independently, identically distributed. This should either be tested or assumed to be true (see IEC 60300-3-5).

In this standard, numerical methods and graphical methods are described to plot data, to make a goodness-of-fit test, to estimate the parameters of the two- or three-parameter Weibull distribution and to plot confidence limits. Guidance is given on how to interpret the plot in terms of risk as a function of time, failure modes and possible weak population and time to first failure or minimum endurance.

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## 2 Normative references (standards.iteh.ai)

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 – Part 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 61810-2, *Electromechanical elementary relays – Part 2: Reliability*

ISO 2854:1976, *Statistical interpretation of data – Techniques of estimations and tests relating to means and variances*

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

## 3 Terms, definitions, abbreviations and symbols

For the purposes of this document, the definitions, abbreviations and symbols given in IEC 60050-191 and ISO 3534-1 apply, together with the following.

### 3.1 Terms and definitions

#### 3.1.1

#### **censoring**

terminating a test after either a given duration or a given number of failures

NOTE A test terminated when there are still unfailed items may be called a “censored test”, and test time data from such tests may be referred to as “censored data”.

### 3.1.2

#### **suspended item**

item upon which testing has been curtailed without relevant failure

NOTE 1 The item may not have failed, or it may have failed in a mode other than that under investigation.

NOTE 2 An “early suspension” is one that was suspended before the first failure. A “late suspension” is suspended after the last failure.

### 3.1.3

#### **life test**

test conducted to estimate or verify the durability of a product

NOTE The end of the useful life will often be defined as the time when a certain percentage of the items have failed for non-repairable items and as the time when the failure intensity has increased to a specified level for repairable items.

### 3.1.4

#### **non-repairable item**

item that cannot, under given conditions, after a failure, be returned to a state in which it can perform as required

NOTE The given conditions may be technical, economic, ecological and/or others.

### 3.1.5

#### **operating time**

time interval for which the item is in an operating state

NOTE “Operating time” is generic, and should be expressed in units appropriate to the item concerned, e.g. calendar time, operating cycles, distance run, etc. and the units should always be clearly stated.

### 3.1.6

#### **relevant failure**

failure that should be included in interpreting test or operational results or in calculating the value of a reliability performance measure

NOTE The criteria for inclusion should be stated.

### 3.1.7

#### **reliability test**

experiment carried out in order to measure, quantify or classify a reliability measure or property of an item

NOTE 1 Reliability testing is different from environmental testing where the aim is to prove that the items under test can survive extreme conditions of storage, transportation and use.

NOTE 2 Reliability tests may include environmental testing.

### 3.1.8

#### **repairable item**

item that can, under given conditions, after a failure, be returned to a state in which it can perform as required

NOTE The given conditions may be technical, economic, ecological and/or others.

### 3.1.9

#### **time to failure**

operating time accumulated from the first use, or from restoration, until failure

NOTE In applications where the time in storage or on standby is significantly greater than “operating time”, the time to failure may be based on the time in the specified service.

### 3.1.10

#### time between failures

time duration between consecutive failures

NOTE 1 The time between failures includes the up time and the down time.

NOTE 2 In applications where the time in storage or on standby is significantly greater than operating time, the time to failure may be based on the time in the specified service.

### 3.1.11

#### B life

#### L percentiles

age at which a given percentage of items have failed

NOTE "B<sub>10</sub>" life is the age at which 10 % of items (e.g. bearings) have failed. Sometimes it is denoted by the L (life) value. B lives may be read directly from the Weibull plot or determined more accurately from the Weibull equation. The age at which 50 % of the items fail, the B<sub>50</sub> life, is the median time to failure.

## 3.2 Abbreviations

ASIC	application specific integrated circuit
BGA	ball grid array
CDF	cumulative distribution function
PDF	probability density function
MLE	maximum likelihood estimation
MRR	median rank regression
MTTF	mean time to failure

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## 3.3 Symbols

$t$	time – variable
$\eta$	Weibull characteristic life or scale parameter
$\beta$	Weibull shape parameter
$t_0$	starting point or origin of the distribution, failure free time
$r^2$	coefficient of determination
$f(t)$	probability density function
$F(t)$	cumulative distribution function
$h(t)$	hazard function
$\lambda(t)$	instantaneous failure rate
$H(t)$	cumulative hazard function
$F_1$	number of failures with failure mode 1
$F_2$	number of failures with failure mode 2
$F_3$	number of failures with failure mode 3

## 4 Application of the techniques

Table 1 shows the circumstances in which particular aspects of this standard are applicable. It shows the three main methods for estimating parameters from the Weibull distribution, namely graphical, computational and WeiBayes, and indicates the type of data requirements for each of these three methods.

**Table 1 – Guidance for using IEC 61649**

Method/ Kinds of data	Graphical methods	Computational methods	WeiBayes
Interval censored	√	NC	√
Multiple censored	√	NC	√
Singly censored	√	√	√
Zero failures	NC	NC	√
Small sample (≤20)	√	NC	√
Large sample	√	√	NC
Curved data	√	NC	NC
Complete data	√	√	√
NOTE NC means not covered in this standard.			

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## 5 The Weibull distribution (standards.iteh.ai)

### 5.1 The two-parameter Weibull distribution

The two-parameter Weibull distribution is by far the most widely used distribution for life data analysis. The Weibull probability density function (PDF) is shown in Equation (1):

$$f(t) = \beta \cdot \frac{t^{\beta-1}}{\eta^{\beta}} \cdot e^{-\left(\frac{t}{\eta}\right)^{\beta}} \quad (1)$$

where

$t$  is the time, expressed as a variable;

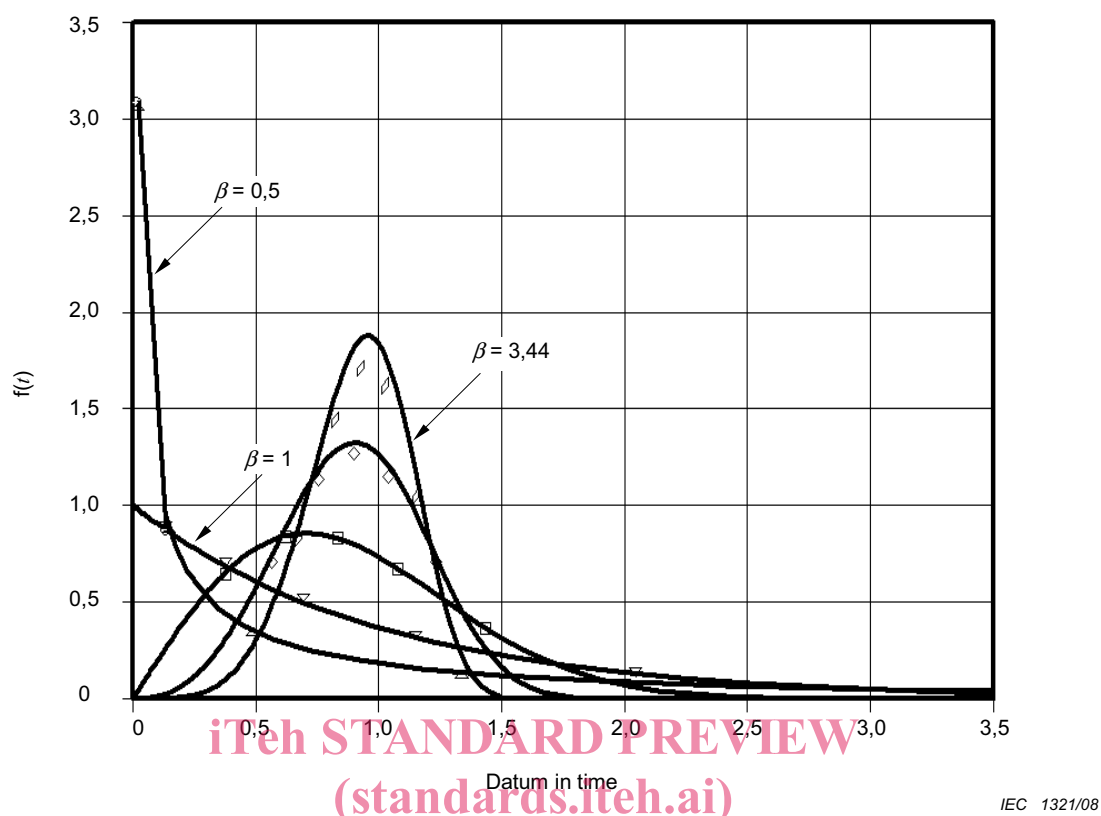
$\eta$  is the characteristic life or scale parameter;

$\beta$  is the shape parameter.

The Weibull cumulative distribution function (CDF) has an explicit equation as shown in Equation (2):

$$F(t) = 1 - e^{-(t/\eta)^{\beta}} \quad (2)$$

The two parameters are  $\eta$ , the characteristic life, and  $\beta$ , the shape parameter. The shape parameter indicates the rate of change of the instantaneous failure rate with time. Examples include: infant mortality, random or wear-out. It determines which member of the Weibull family of distributions is most appropriate. Different members have widely different shaped PDFs (see Figure 1). The Weibull distribution fits a broad range of life data compared with other distributions. The variable  $t$  is generic and can have various measures such as time, distance, number of cycles or mechanical stress applications.



**Figure 1 – The PDF shapes of the Weibull family for  $\eta = 1,0$**

From Figure 1, the PDF shape for  $\beta = 3,44$  (indicated) looks like the normal distribution: it is a fair approximation, except for the tails of the distribution.

The instantaneous failure rate  $\lambda(t)$  (or  $h(t)$ , the hazard function) of the two-parameter Weibull distribution is shown in Equation (3):

$$\lambda(t) = h(t) = \beta \cdot \frac{t^{\beta-1}}{\eta^\beta} \quad (3)$$

Three ranges of values of the shape parameter,  $\beta$ , are salient:

- for  $\beta = 1,0$  the Weibull distribution is identical to the exponential distribution and the instantaneous failure rate,  $\lambda(t)$ , then becomes a constant equal to the reciprocal of the scale parameter,  $\eta$  ;
- $\beta > 1,0$  is the case of increasing instantaneous failure rate; and
- $\beta < 1,0$ , is the case of decreasing instantaneous failure rate.

Characteristic life,  $\eta$ , is the time at which 63,2 % of the items are expected to fail. This is true for all Weibull distributions, regardless of the shape parameter,  $\beta$ . If there is replacement of items, then 63,2 % of the times to failure are expected to be lower or equal to the characteristic life,  $\eta$ . Further discussion of the issues concerning repair and non-repairable items can be found in IEC 60300-3-5. The 63,2 % comes from setting  $t = \eta$  in Equation (2) which results in Equation (4):

$$F(\eta) = 1 - e^{-(\eta/\eta)^\beta} = 1 - e^{-(1)^\beta} = 1 - (1/e) = 0,632 \quad (4)$$

## 5.2 The three-parameter Weibull distribution

Equation (5) shows the CDF of the three-parameter Weibull distribution:

$$F(t) = 1 - e^{-\left(\frac{t-t_0}{\eta}\right)^\beta} \quad (5)$$

The parameter  $t_0$  is called the failure-free time, location parameter or minimum life.

The effect of location parameter is typically not understood well until a poor fit is observed with a 2-parameter Weibull plot. When a lack of fit is observed, engineers attempt to use other distributions that may provide them with a better fit. However, the lack of fit can be reconciled when the data is plotted with a 3-parameter Weibull distribution (see 8.5). Using the location parameter, it becomes evident that the product failures are offset by a fixed period of time, called the threshold. The effect of location parameter is normally observed when a product sees “shelf-life” after which the first failure occurs. A good indicator of the effect of a location parameter is the convex shape of a plot.

## 6 Data considerations

### 6.1 Data types

Life data are related to items that “age” to failure. Weibull failure data are usually life data but may also describe material data where the “aging” may be stress, force or temperature. “Age” may be operating time, starts and stops, landings, takeoffs, low-cycle fatigue cycles, mileage, shelf or storage time, cycles or time at high stress or high temperature, or many other continuous parameters. In this standard the “age” parameter will be called time. When required, “time” can be substituted by any of the “age” parameters listed above.

### 6.2 Time to first failure

The Weibull “time” variable is usually considered to be a measure of life consumption. The following interpretations can be used:

- time to first failure of a repairable item;
- time to failure of an non-repairable item;
- time from new to each failure of a repairable system if a non-repairable item in the system fails more than once during the period of observation. It has to be assumed that the repair (change of the item) does not introduce a new failure, so that the system after the repair can, with an approximation, be regarded as having the same reliability as immediately before the failure (commonly referred as the “bad as old” assumption);
- time to first failure of a non-repairable item, following scheduled maintenance, with the assumption that the failure is related to the previous maintenance.

### 6.3 Material characteristics and the Weibull distribution

Material characteristics such as creep, stress rupture or breakage and fatigue are often plotted on Weibull probability paper. Here the horizontal scale may be stress, cycles, load, number of load repetitions or temperature.

### 6.4 Sample size

Uncertainty with regard to the Weibull parameter estimation is related to the sample size and the number of relevant failures. Weibull parameters can be estimated using as few as two failures; however, the uncertainty of such an estimate would be excessive and could not confirm the applicability of the Weibull model. Whatever the sample size, confidence limits should be calculated and plotted in order to assess the uncertainty of the estimations.