Life time tests

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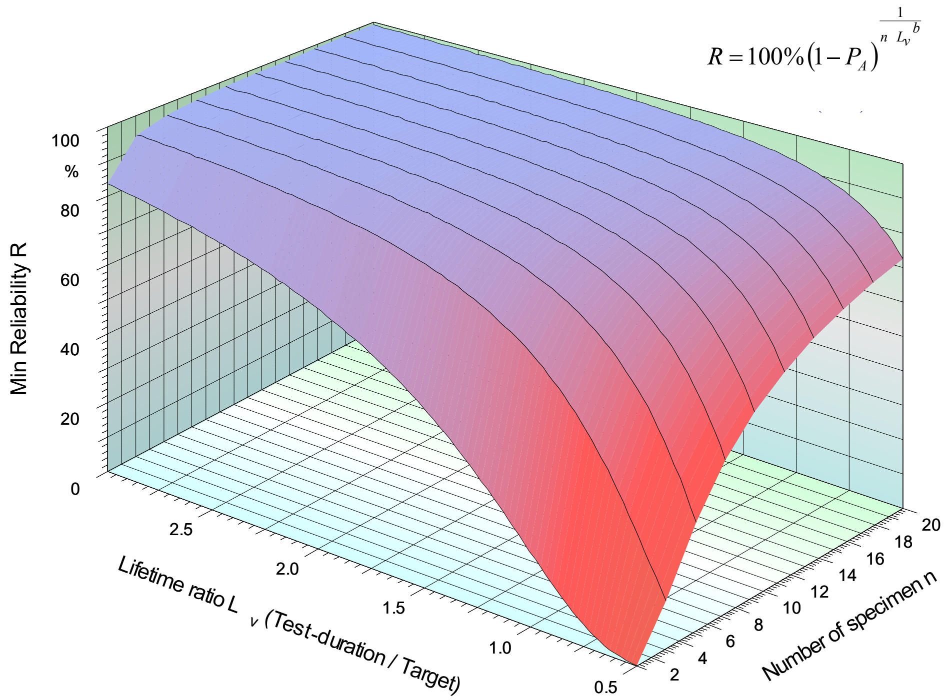
Success Run



Contents

Requirement and related topics

Basics of statistics are beneficial for these descriptions. Further and related topics include:

www.weibull.de/COM/Weibull_Analysis.pdf

Keywords:

Life test, life time tests, success run, reliability, life time ratio, probability assurance, confidence level, acceleration factor, minimum reliability, sample size, Weibull, shape parameter, end-of-life, software

Introduction

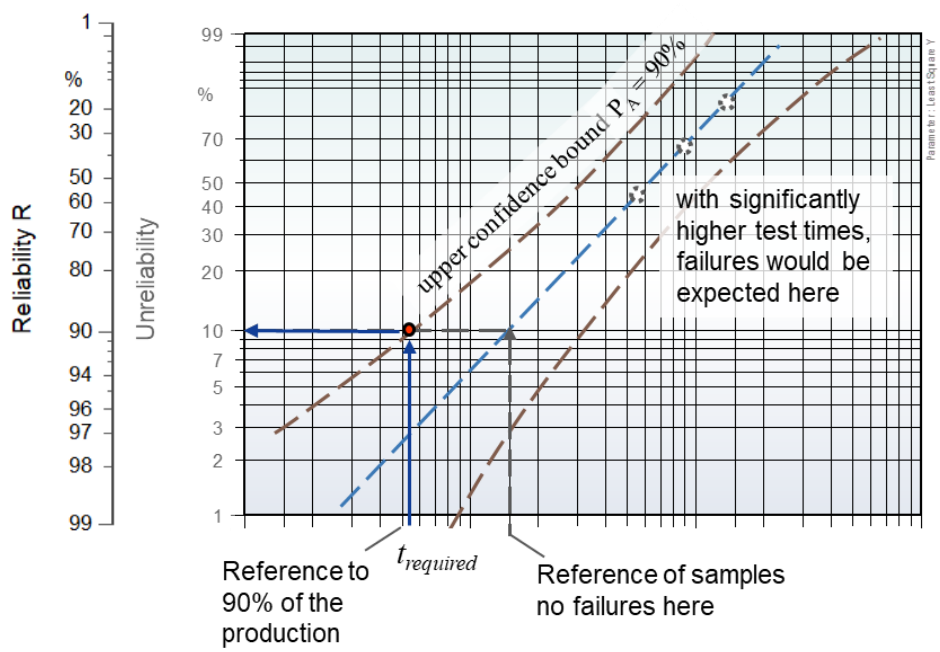
Durability tests are intended to provide statistical information about the expected reliability of parts or components. The goal is to ensure that no test specimens fail during the test. This scenario is therefore also called a success run.

Purpose and benefit

The goal is to make a statement about the minimum reliability R_{min} of the population with the smallest possible sample size n and a specific test duration. This can be used, for example, to verify specifications and approve developments.

Basics

If no components fail during the test, a Weibull evaluation is not possible. The following relationship for success run results from the beta-binomial distribution with x=0 failures and the ratio of a Weibull distribution for the test time to the required lifetime:



Example:

P_A = 90%
R = 90% (H = 10% ⇨ t_{10})

With 90% probability, a "minimum reliability of 90% is to be expected, or a failure probability of not more than 10%.

Since there where no failures, no Weibull net can be created! If, however, you might continue much longer, you would have had enough information (doted points).

P_A : Probability assurance (upper confidence bound)

L_r : Lifetime ratio *
⇨ test time / required time
$L_r = t_{test} / t_{required}$

n : number of tests, respective samples,

b : Shape parameter Weibull-distribution, (slope of Weibull straight line) is usually set to b = 2 (if not empirical values exist))

A conclusion about the population is possible with a probability assurance P_A, which is usually 90%. This probability takes into account the limited statement of the samples in the test to the population in production.
It is the reference to the upper confidence bound in the Weibull net an is also called confidence level.

In the calculation, the test time is related to the required service life and used as the service life ratio L_r. The compression factor κ takes into account a higher load in the test compared to the actual application. For this purpose, a stress level that is as realistic as possible but increased is advisable. Typically, between n = 5-10 test specimens are used. The test time should at least correspond to the required service life, or the following must apply:

$$L_v \cdot \kappa \geq 1$$

For $n \geq 7$ and, for example, R_{min} = 0.90, a failure is mathematically permissible. However, as an additional condition, this failure must not occur when $L_v \cdot \kappa < 1$. In the case of failures, the formula shown in the figure must be replaced with the calculation using χ^2; see the overview of test cases later.

Benefits of Success Run

The greatest advantage of the endurance tests shown is that you don't have to test the components until they fail, which saves a lot of time. By correcting for unexpected failures, there's no risk that the tests were in vain (see the table for an overview of the test cases).

Disadvantages of Success Run

The shape parameter b must be estimated, which has a significant impact on the results. It is not possible to predict the actual lifetime. The cause of failure cannot be determined in a Success Run because no failure pattern is available. Therefore, testing should be continued until end-of-life in the early development phase.

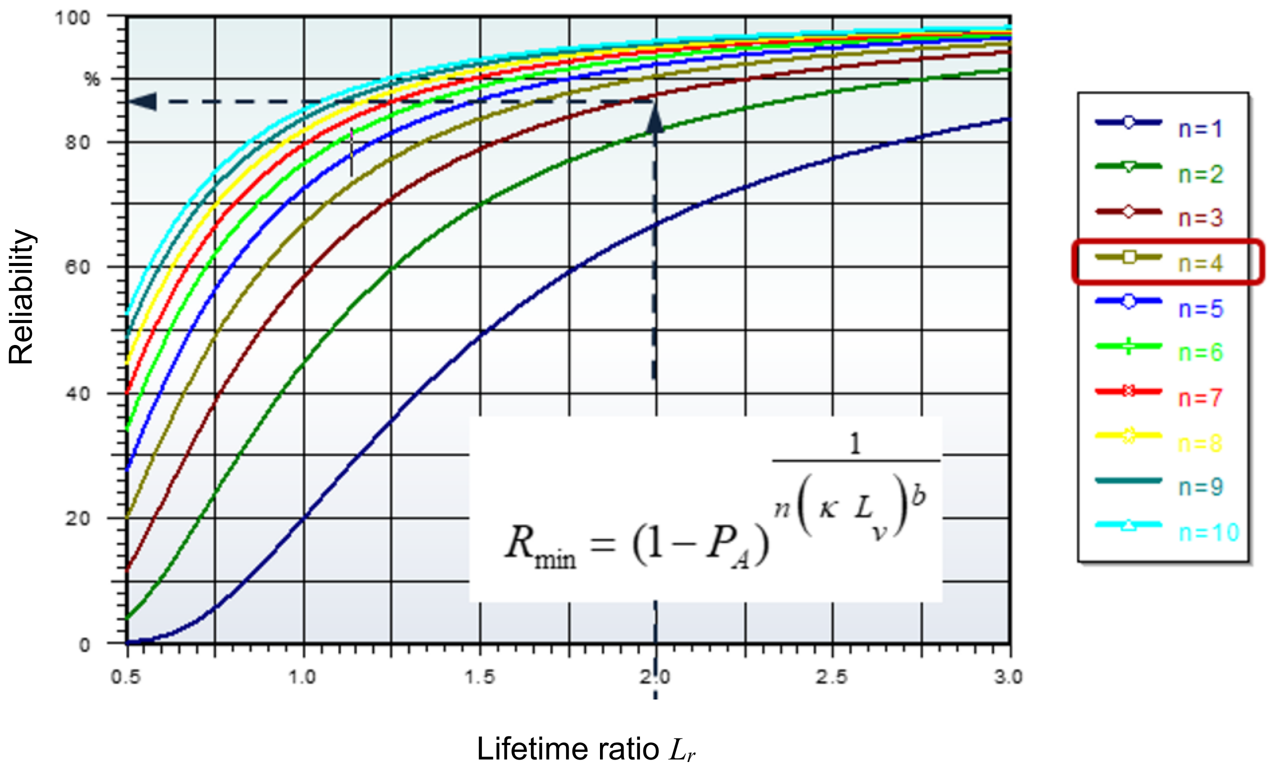
- For reliability, it is better to test fewer "samples" for a longer period.

- However, fewer samples also provide less information about the component's variance!

- In principle, Lv · κ < 1

Example

A component is required to achieve a minimum reliability of 90%. The required service life is 300,000 cycles. With a specified P_A = 0.90, the requirement can be met with n=4 test specimens and a test time of twice the 600,000 cycles.



Consideration of unexpected failures

If any failures occur during the tests, the previous relationship is no longer valid! Instead, the minimum reliability has to be calculated via the c^2 distribution:

$$R_{min} = e^{-\frac{\chi^2_{2x+2;P_A}}{2 \cdot L_r^b \cdot n}}$$

with x = number of failures during the test.
(those failures should not occur below $Lr=1$)

$$n = -\frac{\chi^2_{2x+2,P_A}}{2 \cdot L_r^b \cdot \ln(R_{\min})} \qquad L_r = \left(-\frac{\chi^2_{2x+2,P_A}}{2 \cdot n \cdot \ln(R_{\min})}\right)^{1/b}$$

Example: n=5; b=2; R_{min}=0,80; P_A=0,80

Necessary duration for required min reliability:

No failure L_r = 1,20

1 failure L_r = 1,66

2 failure L_r = 1,98

Overview of test cases

Without failures	With failures
Planned test without failures	Correction in case of failures (calculation via χ2 distribution)
Minimum reliability	
$R_{min} = (1-P_A)^{\frac{1}{n(L_v\kappa)^b}}$	$\mathrm{R_{min}} = e^{-\frac{\chi^2_{2x+2;\,P_A}}{2n(\kappa\, L_v)^b}}$
Sample size	
$n = \frac{1}{(L_v\kappa)^b}\left(\frac{\ln(1-P_A)}{\ln(R_{min})}\right)$	$n = -\frac{\chi^2_{2r+2;P_A}}{2\cdot\ln(R_{min})(\kappa L_v)^b}$
Test duration	
$L_v = \frac{1}{\kappa}\left(\frac{1}{\mathrm{n}}\left(\frac{\ln(1-P_A)}{\ln(R_{\mathrm{min}})}\right)\right)^{\frac{1}{b}}$	$\mathrm{L}_v = \frac{1}{\kappa}\left(-\frac{\chi^2_{2r+2;P_A}}{2\cdot\mathrm{n}\cdot\ln(R_{min})}\right)^{\frac{1}{b}}$

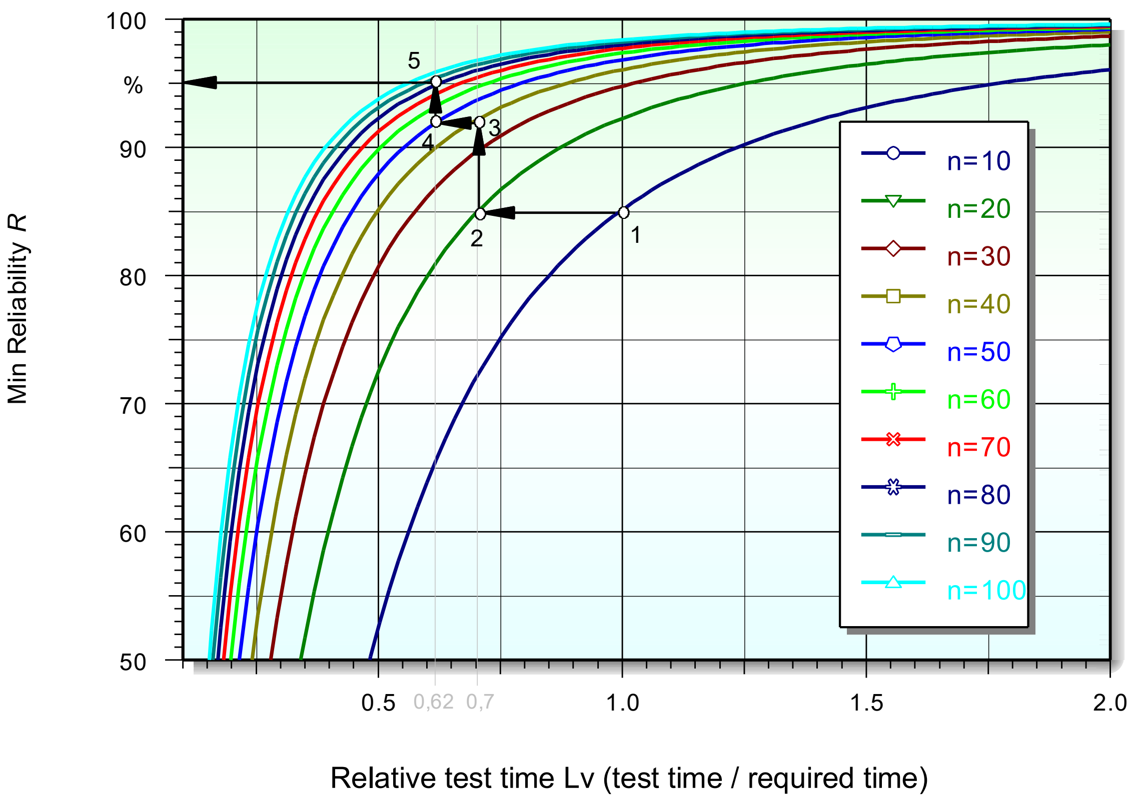
Determining minimum reliability for several test groups with different running times

If there are several identical products with different running times used in the test (or in the field), each running time completed without failure will contribute to deducing the minimum reliability. Corresponding classifications of the running time are preferable formed for this purpose. Example: The following running times and number of "test specimens" serve as the basis for a confidence level of P_A=80% and a required service life of 100,000 km (assumption b=2):

i	Running time/km	Lv	n
1	100000	1.0	10
2	70000	0.7	20
3	62000	0.62	40

The running times were sorted in descending order and the calculation started at the longest running time. This produces the following points in the diagram:

1) 10 parts survived without failing at the longest running time of L_r=1.0
2) This corresponds to a quantity of 20 parts at L_r=0.7 (identical R_{min}).
   20 parts were tested without failure at L_r=0.7
3) Together this results in approx. 40 parts at L_r=0.7
4) This corresponds to a quantity of 50 parts at L_r=0.62 (identical R_{min}).
   20 parts were tested without failure at L_r=0.62
5) Together this results in approx. 90 parts at L_r=0.62



The result is a guaranteed minimum reliability of approx. 95%. Referred to the minimum reliability relationship already introduced, the total $R_{min,ges}$ is generally derived from:

$$R_{\min, ges} = 100\% \left(1 - P_A\right)^{\left(\sum_{i=1}^{k} Lv_i^b \, n_i\right)^{-1}}$$

k = Number of different test times (collectiv)

Taking into account previous knowledge

If previous knowledge of the components is available (Bayes method), it can be taken into account by using the Beyer/Lauster method. This previous knowledge can originate, for example, from predecessor models and is expressed by the value R_o that is valid for a confidence level of P_A=63.2%. The expected minimum reliability is:

$$R_{\min} = \left(1 - P_A\right)^{\frac{1}{n\, L_v^b + 1/\ln(1/Ro)}}$$

In the same way as the factor ϕ defined under /26/ for taking into consideration the applicability of the previous knowledge, it is used here under the term previous confidence level to give:

$$R_{\min} = \left(1 - P_A\right)^{\frac{1}{n\, L_v^b + \phi/\ln(1/Ro)}}$$

The previous information factor ϕ must lie between 0…1. ϕ =0 signifies that no previous information should be used whereas ϕ = 1 means all previous information can be used.

ϕ can, for example, assume the following values when the following applies to the components of the earlier tests:

$\phi = 1$	The components and the tests are identical to the current status or are 100% comparable
$\phi = 0.75$	Components have been slightly modified or the design status is identical but from different manufacturers
$\phi = 0.50$	Components have been partially modified, e.g. material properties
$\phi = 0.25$	Components agree only in terms of their concept (rough estimation)

The preliminary confidence level can also be used to express when the test changed.

The reduced number of samples is therefore:

$$n = \frac{1}{L_v^b}\left[\frac{\ln(1-P_A)}{\ln(R_{\min})} - \frac{\phi}{\ln(1/R_o)}\right]$$

An acceleration factor can be used to take into account different loads from earlier tests. This acceleration factor is discussed in the following sections dealing with the component strength (service life in the Woehler diagram).

Reliability from Binomial-method

In general applies to the statistical assurance without given running time the Binomial-method.

$$P_A = 1 - \sum_{i=0}^{x} \binom{n}{i} (1-R)^i \, R^{n-i}$$

with x = number of failures
n = sample size

R is the the reliability for not defined running time (normally to describe the quality after production). For the representation often the so called “Larson-Nomongram” is used, because the formula can not be resolved for R. Especially in industrial series production the Binomial-method represents an important tool for assessing the quality level for the sampling technique and for the control charts.

In case of no failures (x = 0) the equation becomes the simple form

$$P_A = 1 - R^n$$

which is conform to the success-run-method.

Summary

⇨ For reliability it is better to test fewer samples longer than many samples for a relatively short time

⇨ Fewer samples, however, also means less accurate deduction of the component scatter!

⇨ It should be always $L_r > 1$ if the load cannot be increased

⇨ No part must fail at $L_r < 1$ irrespective of the mathematical minimum reliability (minimum requirement)

Application in Visual-XSel

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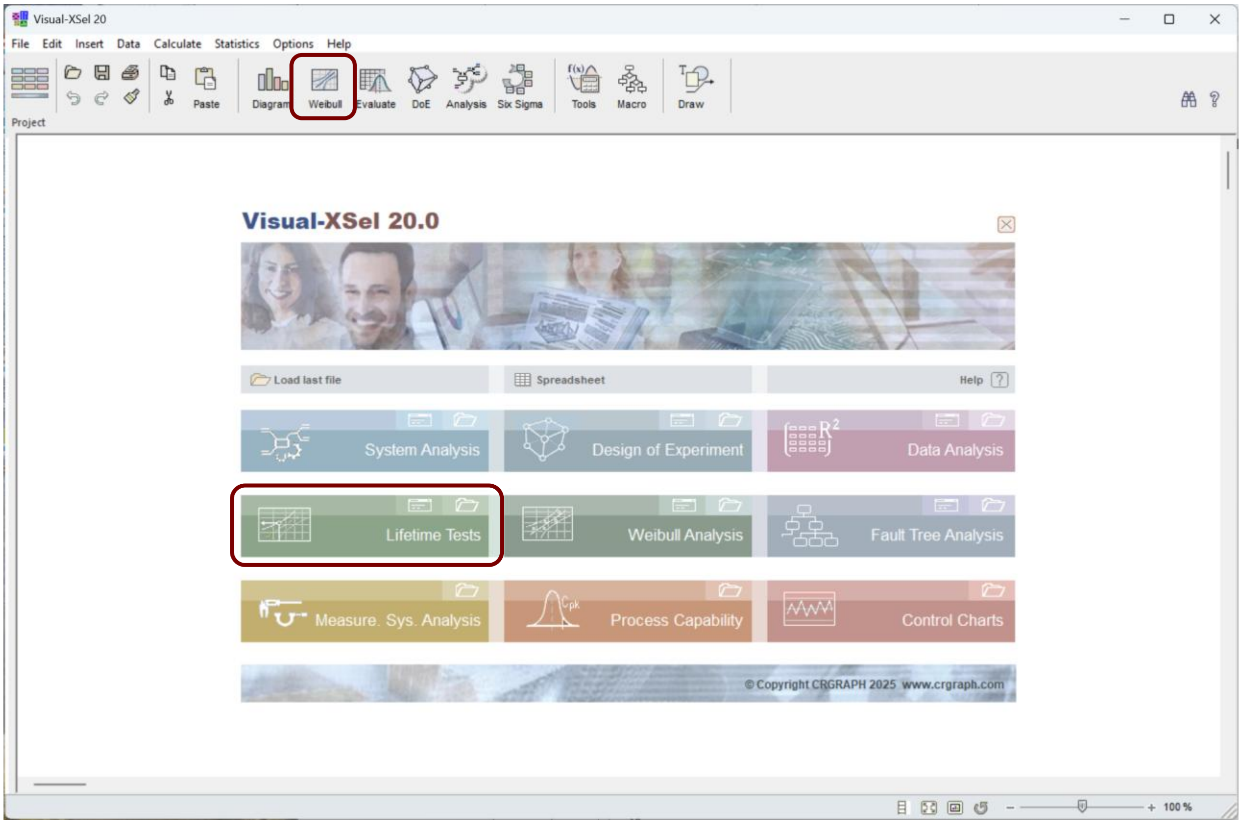
Our software Visual-XSel is a powerful tool for all important statistical quality and reliability methods. To get started, use the topic areas in the guide (see also crgraph.de/en/search-index), or the icon **Weibull**.



Here you can find an introduction and a short video:
crgraph.de/en/visual-xsel-software/

Here you can also find some introductory videos:
crgraph.de/downloads/software/Visual-XSel_Basis_Functions.mp4
crgraph.de/downloads/software/Visual-XSel_Methods.mp4

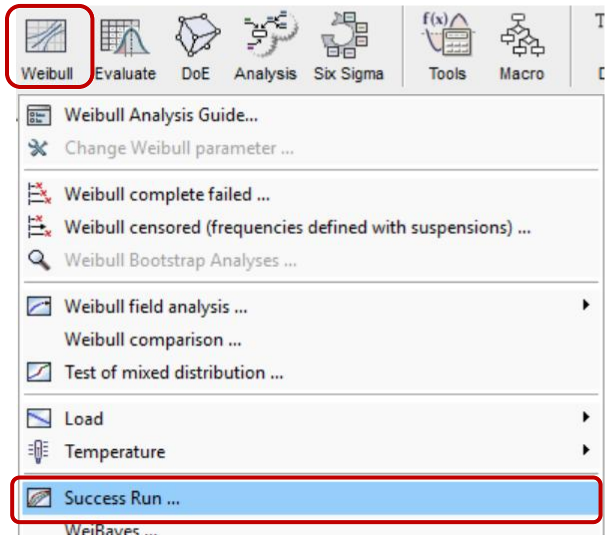
It is not for nothing that this software is used in many well-known companies:
References

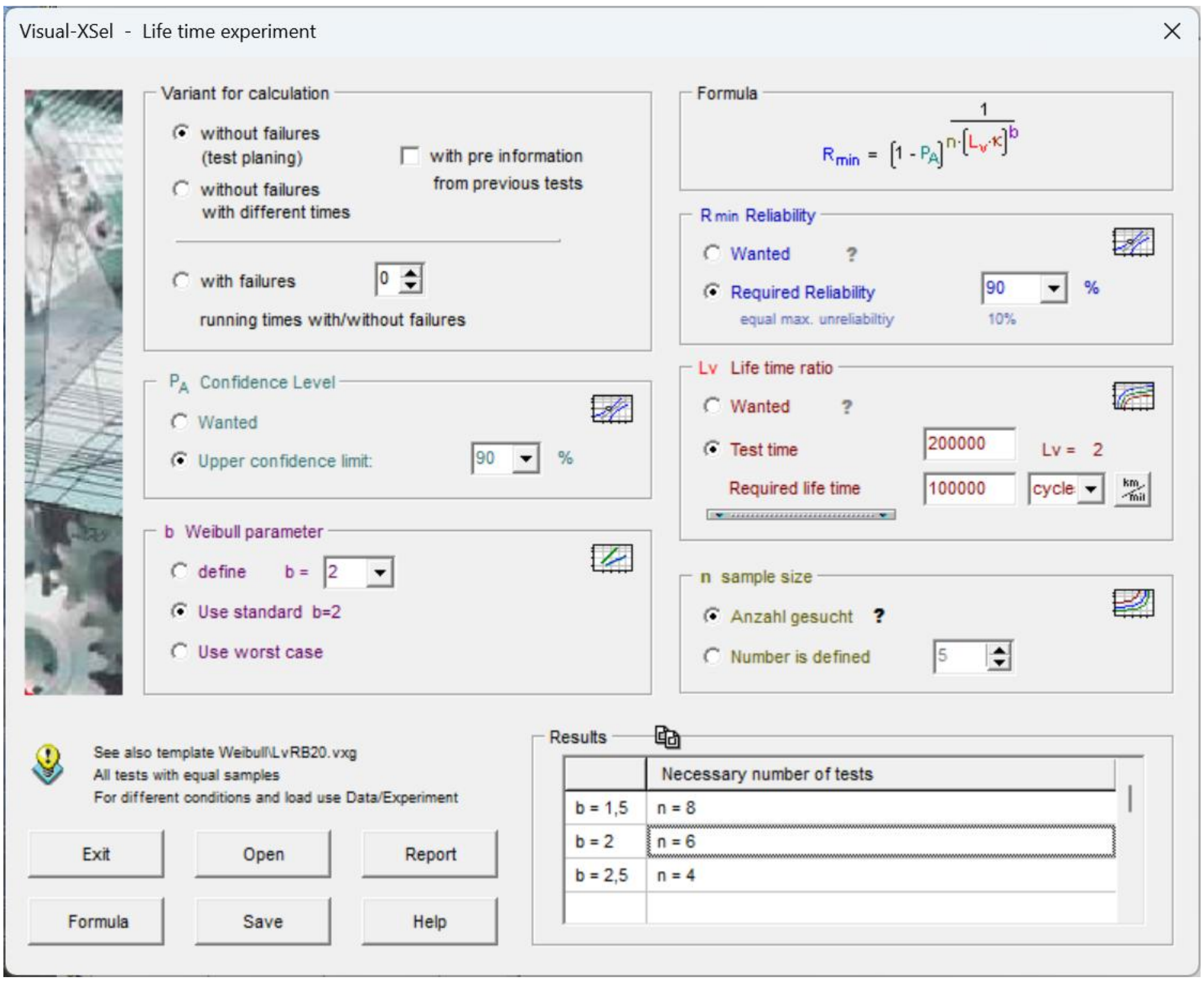
The following description is a guide and introduction to the topic shown

Via the main guide or the icon Weibull the required reliability, the necessary test duration or the sampling size can be calculated. For this a default information is the confidence level.

In the dialog it is recommended to go step by step from the top left to the right bottom.

In the dialog below there is shown an example of a needed sampling size for a required reliability of 90%. The Weibull-parameter b was estimated by b=2. It is shown what was needed if instead b=1.5 or b=2.5 would have been.





The example with several test groups is:

If here is the requirement P_A = 90% and R_{min} = 90% the table of results show how many tests must be added to achieve the R_{min} = 90%: