Process Capability Studies

Definition

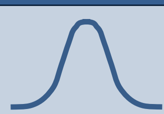
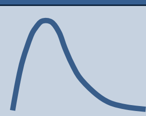
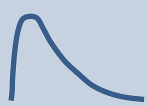
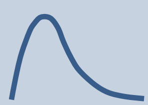
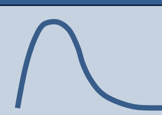
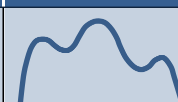
The quality of a production process is subject to certain fluctuations. What are known as capability indexes are calculated so that these processes can be assessed, with a broad distinction being made between machine capability studies on the one hand and process capability studies on the other.
Both are designed to identify and evaluate random and also systematic influences.

Procedure

The specialist department shall stipulate the properties definitive for the capability indexes. It is impractical to apply process capability to each individual part. Instead of this function-critical or quality-critical properties of the assembly should be considered.
Single parts that are not capable by themselves, can be classed and paired so as to achieve a capable functional dimension in the assembly, for example the bearing shell and crank pin. If re-adjustment takes place in final assembly, the process property of the finished product shall be assessed, e.g. body parts and their gap dimensions.

Fundamentals

The distributions to be used are:

	Normal distribution	Folded normal distr. B1	Folded normal distr. B2	Log-normal distribution	Weibull distribution	Mixed distribution
Form						
Exampl.	Geometric dimensions e.g. diameter, length, etc.	Properties limited on one side, e.g. roundness, parallelism	Properties limited on one side, e.g. imbalance, co-axiality	Properties limited on one side, e.g. true-running	Properties limited on one side, e.g. with time reference	Con-mingling of process fluctuations, e.g. machines, batches, etc.
Param.	2-parameter (Gaussian standard)	Negative proportions are mirrored at x=0	Corresponds to Weibull distribution with b=2	2-parameter	2- or 3-parameter	Only triple mixed distribution on basis of proportional normal distribution allowed
Calculation	Calculation analytic by μ + σ	Calculation analytic with folding <> 0	Calculation by least-square Δy	Calculation analytic by median & scatter factor	Calculation by least-square Δy	Calculation analytic, percentile method
Formula	$C_p = \frac{USL - LSL}{6s}$	$C_{pk} = Min\left(\frac{X_{50\%} - LSL}{X_{50\%} - X_{0,135\%}} ; \frac{USL - X_{50\%}}{X_{99,865\%} - X_{50\%}}\right)$				

Important notes:

1.) Invariably, distributions are assigned with the technical context taken duly into account. In the case of the roundness property, for example, the distribution to be used is the folded normal B1, even if the statistical test would accept a normal distribution.

2.) In a folded normal distribution, the mean value is determined from the data and not set to 0 (folding <> 0).

3.) A mixed distribution shall be used only if the normal distribution is rejected by the statistical test!

The folded normal distributions for standard properties are given as follows:

In addition to the normal distribution, e.g. for a unit of length, additional distribution types exist for the subsequent characteristics:

LN* Log-normal distribution

B1 Folded normal 1st type

B2 Folded normal 2nd type

* If LN is not offered in the evaluation strategy it can be mapped by using the 3-parameter Weibull distribution.

Characteristic	Symbol	Distribn.
Straightness	⏤	B1
Levelness	⏥	B1
Roundness	○	B1
Cylindrical shape	⌭	B1
Linear shape	⌒	B1
Surface shape	⌓	B1
Roughness		B1
Imbalance		B2
Parallelism	∥	B1
Perpendicularity	⊥	B1
Slope/angularity	∠	B1
Position	⌖	B2
Coaxiality, concentricity	◎	B2
Symmetry	⌯	B1
Concentricity	⌰	B1/B2
Linear movement	⌰	B1, LN*

Machine capability study

A machine capability study reveals the short-term scatter and the production and repeat precision of the machine when, under near-series conditions, only machine-related influences apply. This is sometimes also referred to as a **short-term capability study**. The purpose of the study is to ascertain a machine's capability with regard to the production process. In principle, a machine capability study has to be conducted for each new machine in the framework of acceptance testing. Reasons for deviations from this standard practice shall be given and the deviations documented.

Calculation of the indexes for process capability

Evaluation is carried out entirely in accordance with the evaluation strategy described in the Appendix.

The relationships as stated below shall apply for properties with normal distribution (standard deviation ascertained by single-sample strategy, verification of normal distribution by the Anderson-Darling test.

$$C_m = \frac{USL - LSL}{6s} \qquad C_{mk} = Min\left(\frac{USL - \bar{x}}{3s}, \frac{\bar{x} - LSL}{3s}\right)$$

where $\bar{x}$ and s are calculated from the specified sample.

For all other properties with non-normal distribution, such as folded normal distribution, for example, calculation shall be by analogy with the descriptions for process capability.

Requirement for machine capability

The requirement is satisfied if:

$C_m \geq 1.67$; $C_{mk} \geq 1.67$

Sample size

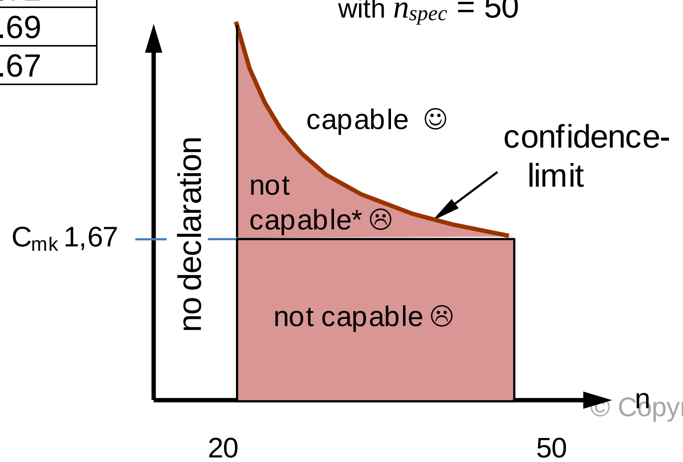
Sample size shall be 50. Parts manufactured in direct sequence shall be removed from the machine. The prerequisite is that production of these parts must be under series conditions.

In justified exceptions, for example short-run production, a smaller sample size is possible but shall be documented (evaluation is impractical with fewer than 20 parts). If the sample size is less than 50, the requirement applies with reference to the lower confidence limit (confidence interval 95%, table by analogy with VDI/VDE 2645):

n	C_{mk}
20	1.93
25	1.85
30	1.79
35	1.75
40	1.72
45	1.69
50	1.67

$$c_{mk} \geq 1{,}67 \frac{\left(1+\frac{1}{2\,n}\right)\sqrt{\frac{n-1}{\chi^2_{n-1,\alpha}}}}{\left(1+\frac{1}{2\,n_{soll/spec}}\right)\sqrt{\frac{n_{soll/spec}-1}{\chi^2_{n_{soll/spec}-1,\alpha}}}}$$

with $n_{spec} = 50$



* C_{mk} ≥ 1.67 for existing plant, e.g. on repeat acceptance testing after repair or other modifications, also permissible for sample sizes n<50 (no provision for confidence interval made)

Boundary conditions

The capability study shall also be conducted after repairs, on a change of production, after modification to the machine and/or relevant part properties and on production of new parts. Necessary interventions shall be documented (planned interventions can be routine adjustments to the process necessitated by a trend). If an unplanned intervention is necessary the study shall be restarted from the beginning. Data shall not be sorted out (see example in the Appendix, isolated outliers are the exception, proved by a statistical outlier test and with technical reason).

A machine capability study shall be conducted regularly for threaded fastener technology, with the concurrence of the specialist department. Other, agreed regulations shall be applied.

Process capability studies

Process capability studies, also known as **long-term capability studies**, establish the long-term quality capability of the entire process. A study of this nature aims at taking all the influencing variables listed below duly into account. A process capability study is the prerequisite for process monitoring/steering, particularly with control charts or statistical process control (SPC).

A process capability study is conducted for the first time when a new process is introduced. The process capability study has to be repeated at least when, for example, a relocation or a serious change in the production process has taken place. Information indicating which changes necessitate this is set out in the production-process and product-release process (see VDA Volume 2).

Calculation of the indexes for process capability

Evaluation is carried out entirely in accordance with the evaluation strategy described in the Appendix.

Properties with normal distribution

The relationships as stated below shall apply for properties with normal distribution (standard deviation ascertained by single-sample strategy, verification of normal distribution by the Epps-Pulley test (n>1000 χ^2 test). Alternatively, the Anderson-Darling test can also be used.

$$C_p = \frac{USL - LSL}{6s} \qquad C_{pk} = Min\left(\frac{USL - \bar{x}}{3s}, \frac{\bar{x} - LSL}{3s}\right)$$

Note: The sample sizes were grouped for calculation of s in the formula above.

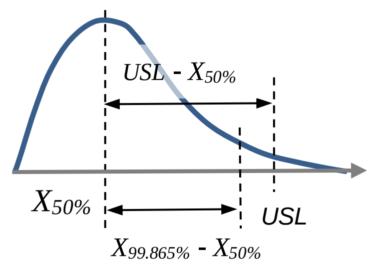
$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}$$

n : scope of complete data

Properties with non-normal distribution

For all other properties with non-normal distribution and upper specification limit only (natural lower limit at 0):

$$C_{pk} = C_{pkU} = \frac{USL - X_{50\%}}{X_{99,865\%} - X_{50\%}}$$



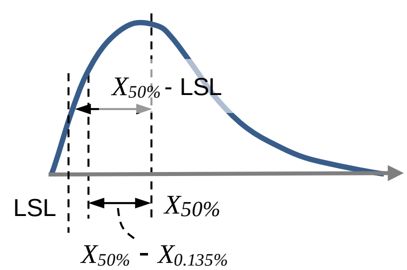
$X_{50\%}$ = median

If there is a lower specification limit as well, for example for minimum surface roughness, C_{pu} has to be calculated as well:

$$C_{pkL} = \frac{X_{50\%} - LSL}{X_{50\%} - X_{0,135\%}}$$

Process capability is then expressed as:

$$C_{pk} = Min\left(\frac{X_{50\%} - LSL}{X_{50\%} - X_{0,135\%}} ; \frac{USL - X_{50\%}}{X_{99,865\%} - X_{50\%}}\right)$$



Requirement for process capability

The requirement is satisfied if:

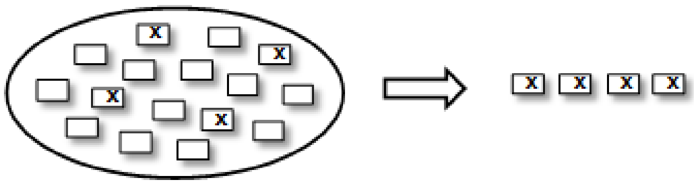
$C_p \geq 1.33$; $C_{pk} \geq 1.33$

Process capability shall be verified no later than three months after the start of standard production.
The measured data of the machine capability study cannot also be incorporated into the process capability study, because long-term influences are not taken into account in the machine capability study.

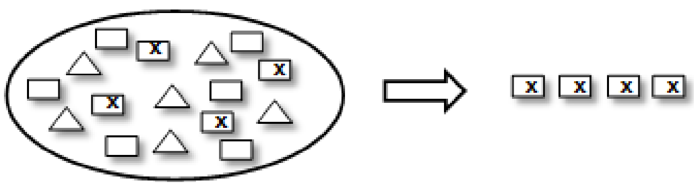
Sample size

In this instance 'sample size' means the total number of measurements taken to calculate the C_p and C_{pk} indexes. Split, usually cyclic single samples n_i are needed for the purpose of ascertaining whether a process is stable.

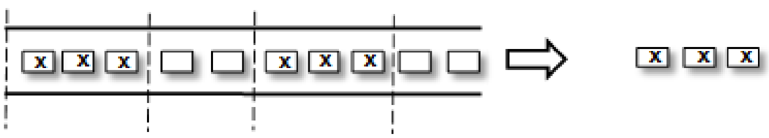
The total size of the sample is defined as 125, individual samples to be taken uniformly from production over a period of 10 to 20 weeks, or over 4 weeks at least. Ensure that the process proceeds under series conditions when sampling is in progress and is not disrupted or changed. An intervention is permissible only between samples and shall be documented. If parts are removed only in samples, the possibilities include the following:



Random samples



Random samples from subgroups



Cyclic removal from process in progress

Ensure that process-changing influences are taken into account, for example tooling and set-up processes, shift changes, batch changes (raw material), etc. The single samples n_i mentioned above shall be defined accordingly and should be at least 5 in number.

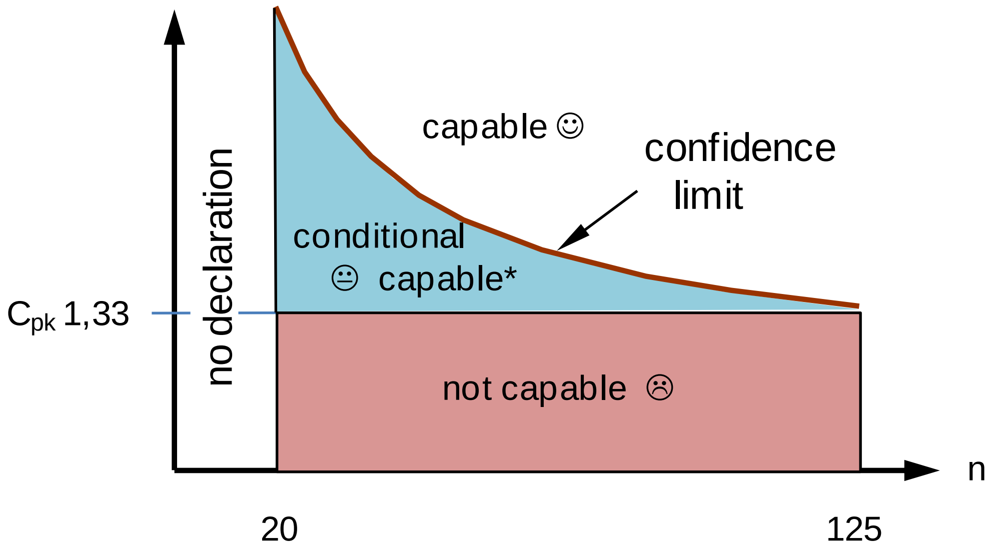
In justified exceptions, for example short-run production, a smaller sample size is possible but shall be documented (min n≥20). Data shall not be sorted out (see example in the Appendix, isolated outliers are the exception, given technical reason, or proved by a statistical outlier test).

If the sample size is n < 125, the requirement applies with reference to the lower confidence limit (confidence interval 95%, table by analogy with VDI/VDE 2645).

n	$C_{pk} \geq$
20	1.67
25	1.59
30	1.54
40	1.48
50	1.44
60	1.41
70	1.39
80	1.37
100	1.35
125	1.33

$$c_{pk} \geq 1.33 \frac{\left(1+\frac{1}{2\,n}\right)\sqrt{\frac{n-1}{\chi^2_{n-1,\alpha}}}}{\left(1+\frac{1}{2\,n_{spec}}\right)\sqrt{\frac{n_{spec}-1}{\chi^2_{n_{spec}-1,\alpha}}}}$$

with $n_{total} = 125$



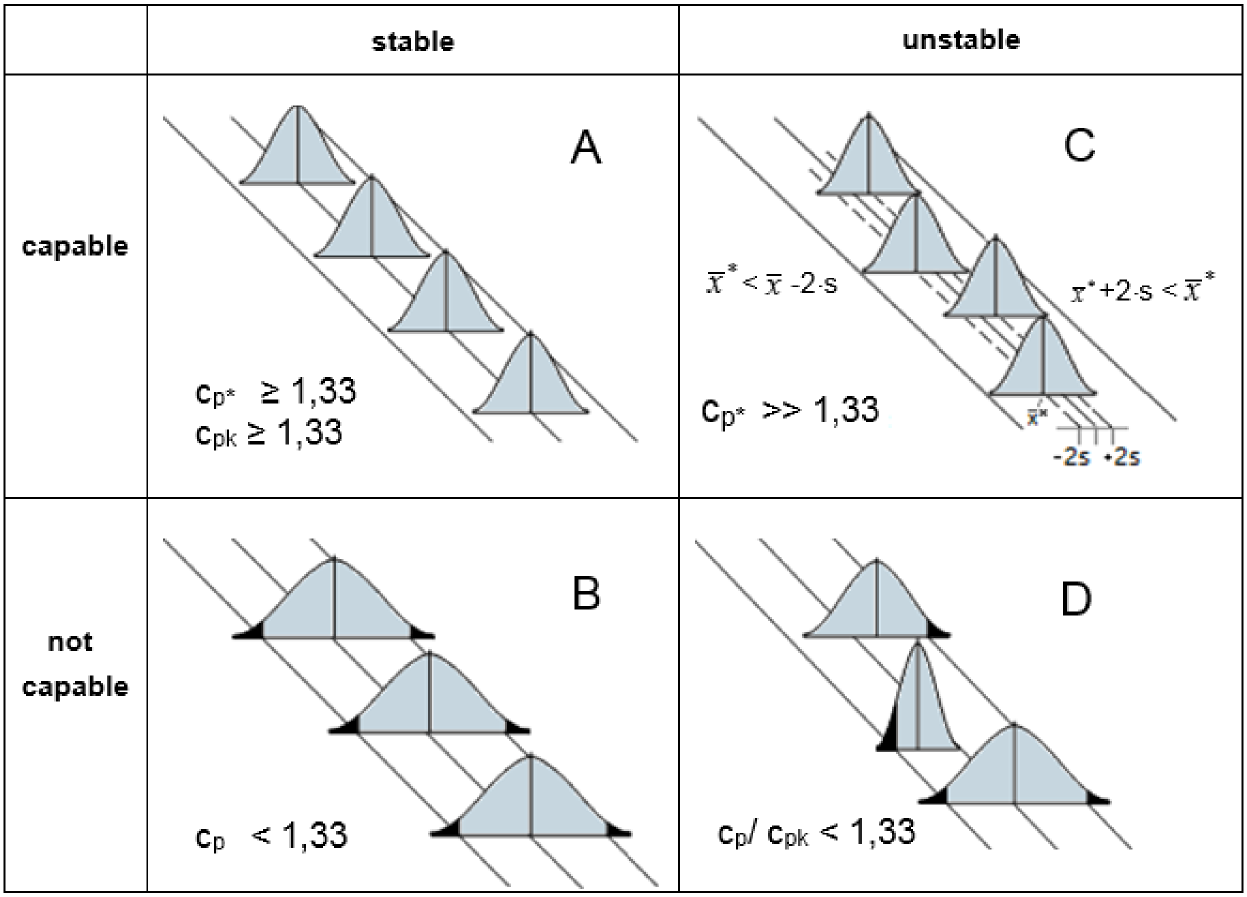
* Conditionally capable is not permissible for specified criteria, L and S classifications and category-A threaded fasteners!

Boundary conditions

In order for the indexes to the calculated the process data must correspond to the statistical basics such as stability and controllability. Capability and stability are prerequisites for a forecast of the process. This should be taken as meaning that the capability indexes are not merely used to describe the performance of a process but they serve for reliably mapping how the process can be expected to perform in the future.

If capability indexes are calculated with non-stability (non-controllability) as a hypothesis, the risks involved with application of these factors is borne by the process owner. These calculated values are merely for a process description; they do not reflect on capability.

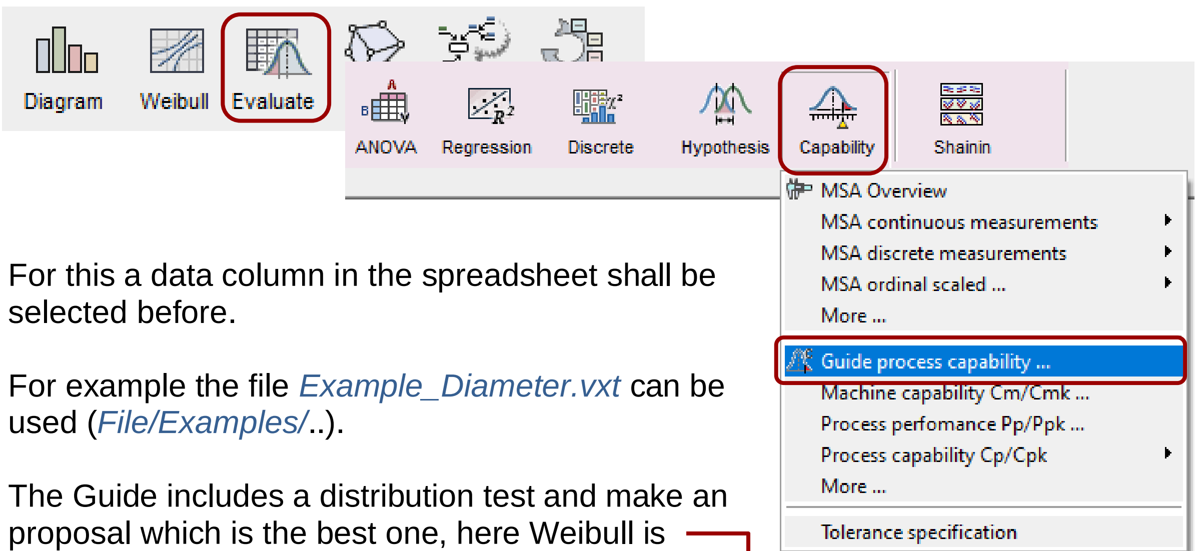
Processes are described by their capability and stability. In simplified terms, processes can be said to be in the following possible states:



These states are identified by dividing the data, for example from the process capability study or from control charts, chronologically into single samples, see section *Sample Size*. State A is preferable to all others. It indicates that the process is both capable and stable. This state shall be achieved, because is returns no rejects in practice.
State C, although capable, is not stable or controlled, no reliable forecast can be made regarding future capability. A position consistently to one side of the mean values is also undesirable. The suggestion is: if the distributions of the single samples are one-sided at the lower or upper tolerance limit, the mean value $\bar{x}_i$ shall be no more than within $\pm$ 25 % of the tolerance middle. For normalized consideration this means a maximum mean value offset of $\pm$ 2s. In this instance standard deviation s is related to the process capability study with n = 125. Note that this is applicable only to processes with unavoidable drift, for example the "allowance" for tool wear. If C_p is not significantly greater than 1.33, in the control chart, the warning limit will frequently be overshot and the probability of violation of the control-intervention limit increases accordingly! Establish the cause of fluctuation (e.g. tool changes, batches, shifts). Design of experiment (DoE) tests can be applied to quantify the effects of the influences.
In state B it is necessary either to improve the process toward A or introduce suitable measures to prevent the dispatch of faulty units.

Using Visual-XSel 17.0

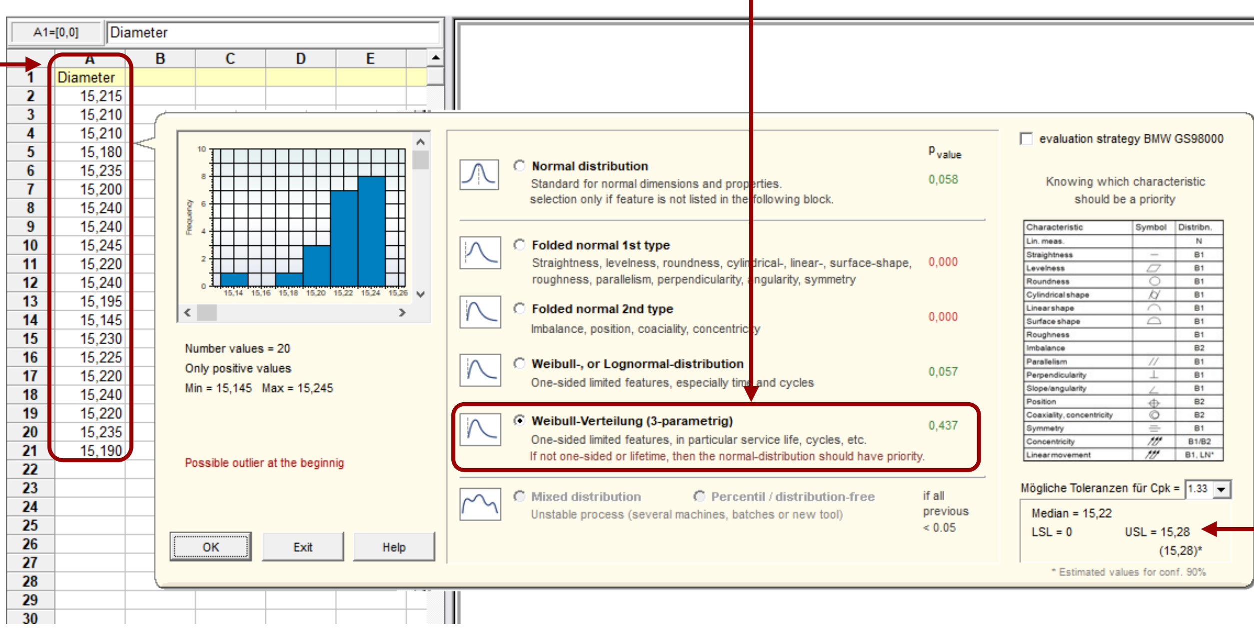
All procedures and analyses are carried out via templates. There are several possibilities to open them. The direct way is via the selection in the start guide, or via the icon Evaluate/ Capability. The recommended item here is the *Guide process capability ….*



For this a data column in the spreadsheet shall be selected before.

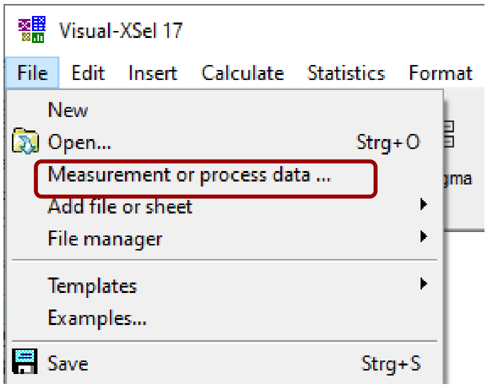
For example the file *Example_Diameter.vxt* can be used (*File/Examples/*..).

The Guide includes a distribution test and make an proposal which is the best one, here Weibull is recommended, because of the best (highest) p-value (see *www.weibull.de/COM/Hypothesis_Tests.pdf)*

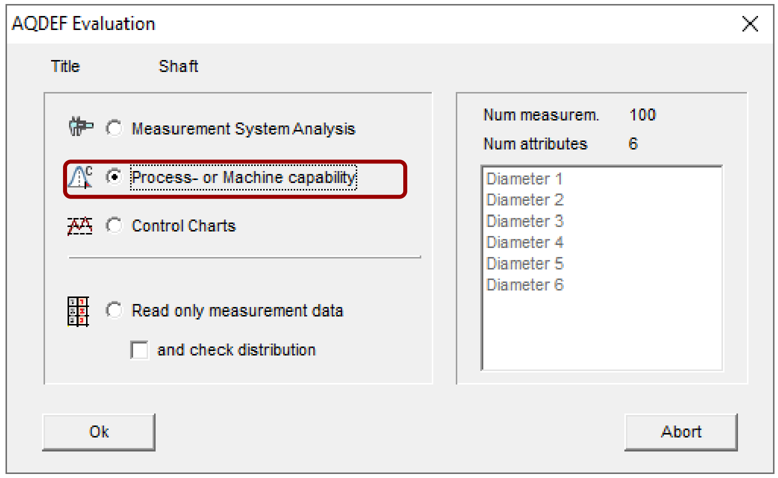


A new option in Visual-Xsel 17.0 is a calculation of a needed limit to achieve a wanted C_{pk} – value.
If you select the button *OK* the relevant template will be loaded.

In version 17.0 there is a new menu item to load directly measurement data in the AQDEF® format.
www.q-das.com/en/service/data-format-aqdef



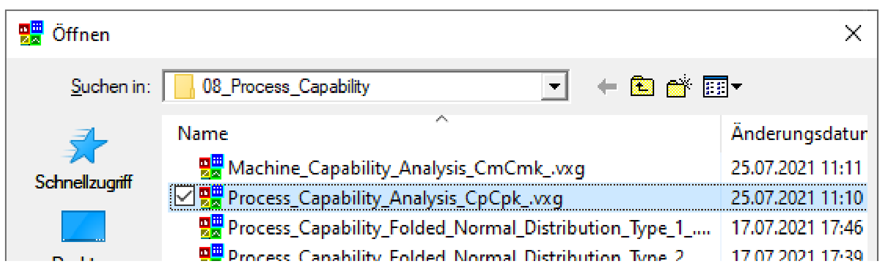
After loading one can select the analysis method.



On the right side the existing attributes are show and can be select later.

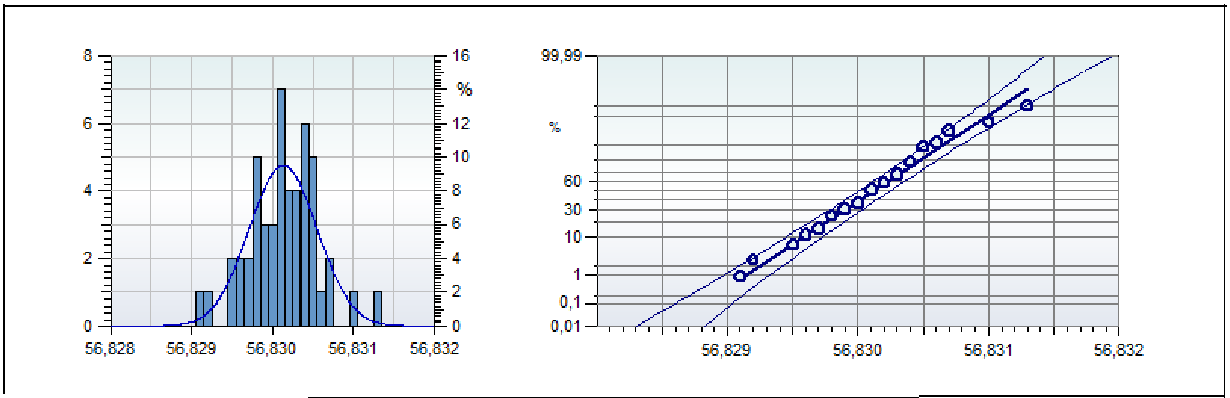
By using the first three options the relevant templates with an underscore *_.vxg are shown here, as a sign for the AQDEF® format.

After loading the source data, please select the wanted method, for example the Process Capability Analysis Cp/Cpk. The evaluation (macro) starts here automatically.



For templates without an underscore *_.vxg the macro has to be started manually. The instructions in the speech bubbles will guide you through the procedure here.

The output for the example of the normally distributed process capability for the template *Process_Capability_Analysis_Cpk._vxg* is:



Specification		Measured values		Statistical values	
Sollwert x_{soll}	56,830	x_{min}	56,829	$\bar{x}$	56,830
Toleranz T	0,0040	x_{max}	56,831	$\bar{x}$ -3s	56,829
		R	0,0022	$\bar{x}$ + 3s	56,831
		n_{ges}	50	6 s	0,0025
				s	0,0004

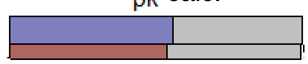
Normal distributed

$C_p = \frac{T}{6 \cdot s}$ 1,272 ≤ **1,585** ≤ 1,898

$T_{min/Cp=1,33}$ 0.0034

$C_{pk} = Min\left(\frac{OSG-\bar{x}}{3 \cdot s};\frac{\bar{x}-USG}{3 \cdot s}\right)$

C_{pk} calc.



$C_{pk\,ist}$: 1,175 ≤ **1,482** ≤ 1,790

C_{pk} required*
1.442

$T_{min/Cpk\ required}$ 0.0039

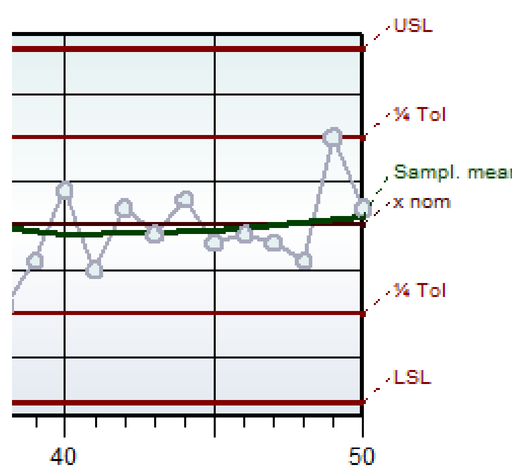
Process capable (Cp, Cpk) and stabil

If a confidence calculation for the C_{pk} is selected and the number of repetitions is less than 125, the C_{pk} required has a higher value than 1.33.

On the right side, a minimum tolerance is displayed, which is necessary to meet exactly the requirement. If the process capability is not achieved, it is possible to extend the tolerance, if this is possible for the function of the characteristic.

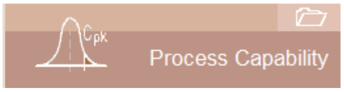
Stabil process

Whether a process is stabil, that can be judged in the chart on page 2. The mean of the defined sample size should lie inside ±1/4 Tol. Otherwise the process is considered as not enough stabil.



Process-/Machine-Capability “Quick – Test”

To proof several attributes the template *Process_Capability_Cpk_QuickTest.vxg* or *Machine_Capability_Cmk_QuickTest.vxg* is useful. To open this template the following steps are necessary. Open Visual-XSel or use the menu *File/New*. Click to the icon Capability

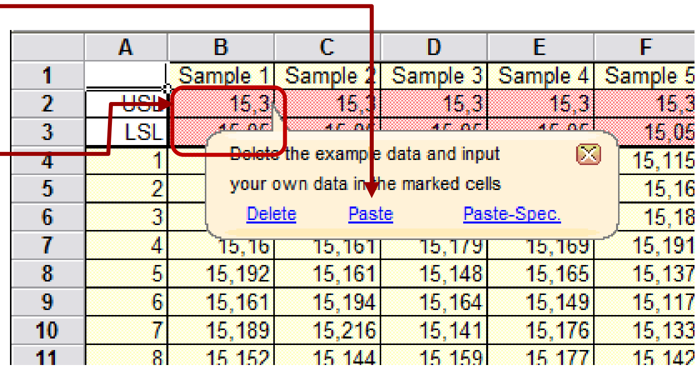


or use *File/ Templates/ Capability*….

Open one of the templates and follow the speech bubble.

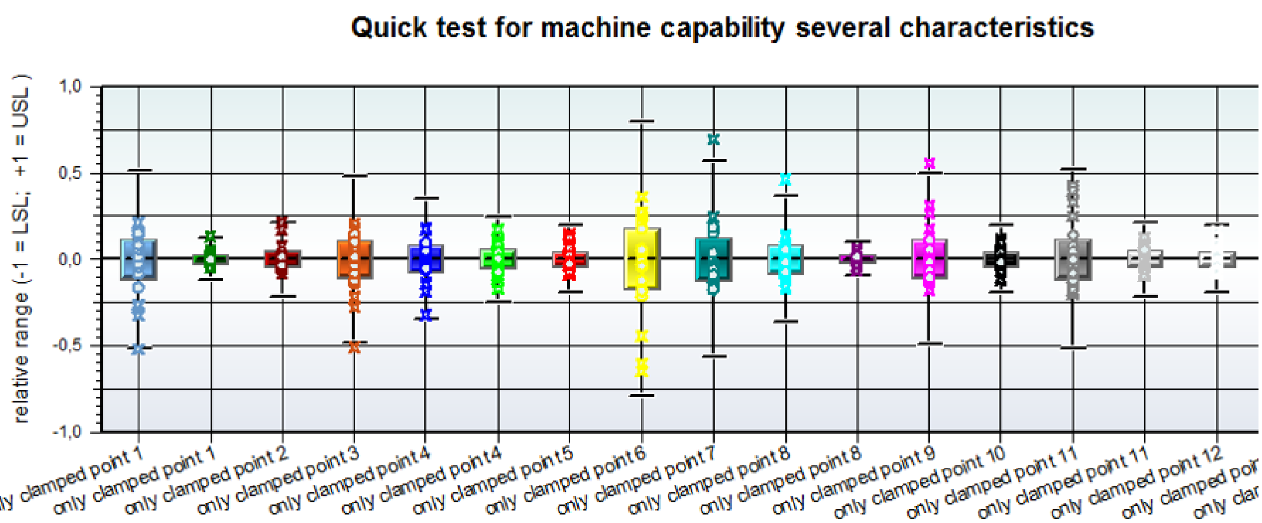
Fill your data by using the Link „Paste“ in the speech-bubble.

Then fill manuel the USL/LSL before starting the macro with F9 or with the icon where the next speech-bubble appears.



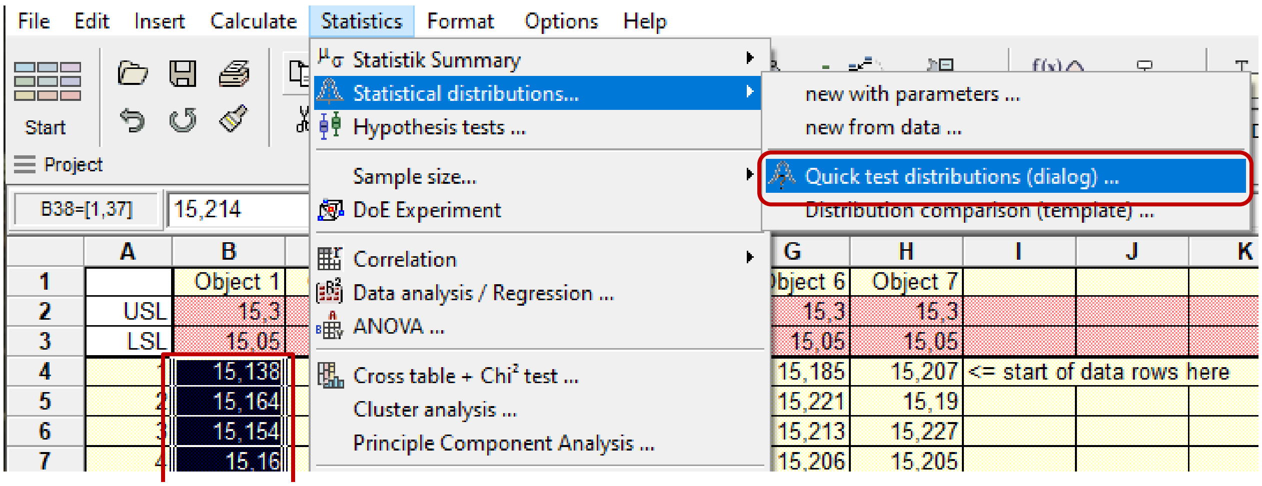
The results are listed above the Box plots. It is recommended to use a confidence for C_{pk}, which regards the sample size (C_{pk}-limit).

The data columns are displayed via normalized box plots, i.e. the values are related to the USL-LSL range. This allows different units and value ranges to be compared side by side.

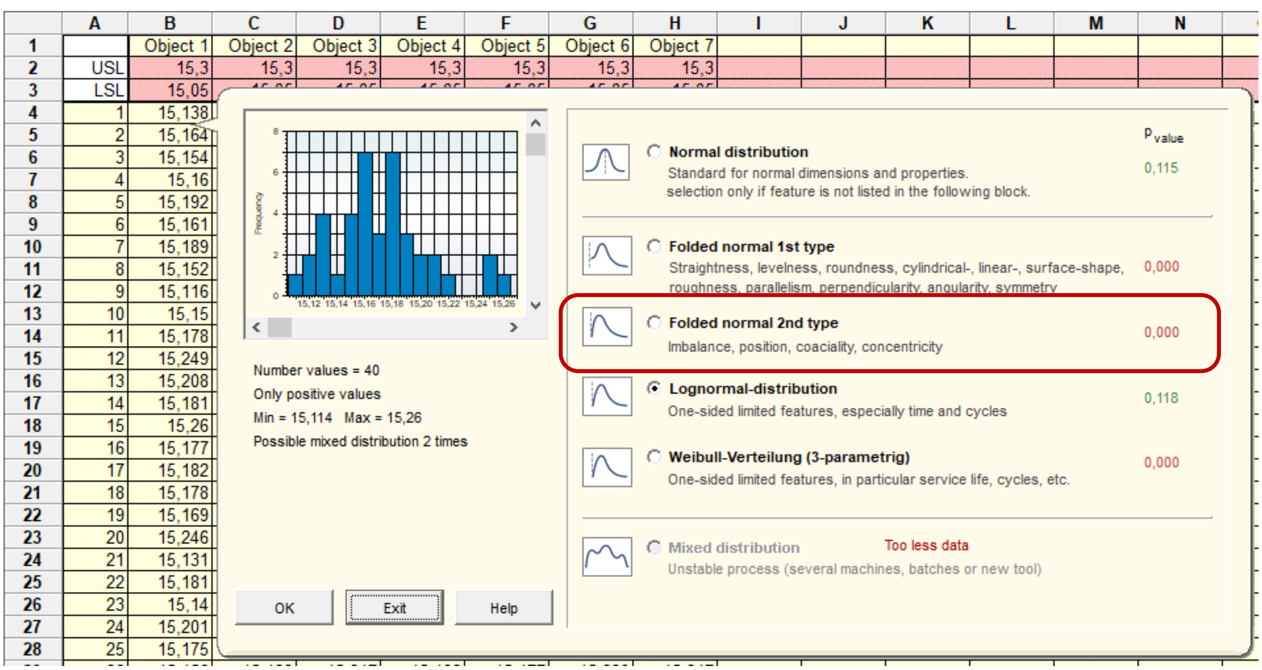


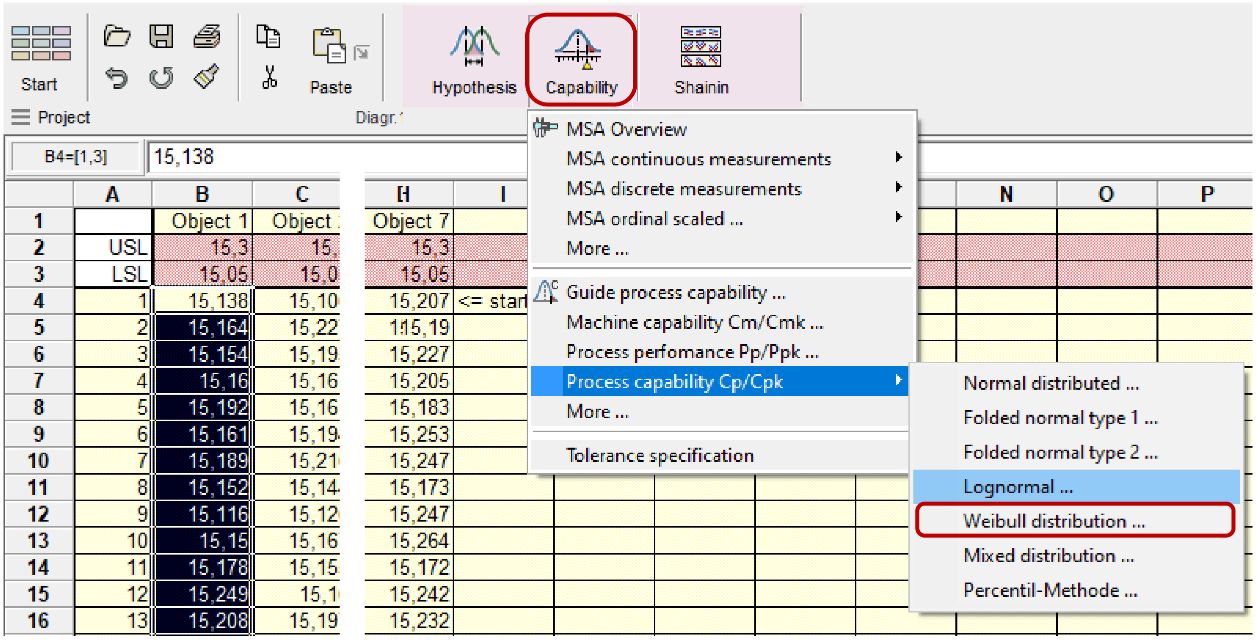
	xm	s	LSL	USL	Min	Max	Cm	Cmk	Cmk limit*	p-value	n
only clamped point 1	0,066	0,086	-0,434	0,566	-0,194	0,173	1,935	1,934	1,818	0,000	27,000
only clamped point 1	-0,022	0,020	-0,522	0,478	-0,047	0,044	8,294	8,290	1,818	0,063	27,000

If one or more attributes are not normal distributed (p-value<0.05), it has to be checked an alternative distribution.
For this go into the spreadsheet /table T1 and mark the data for the regarded column <u>beginning at row 4</u> and use the following menu

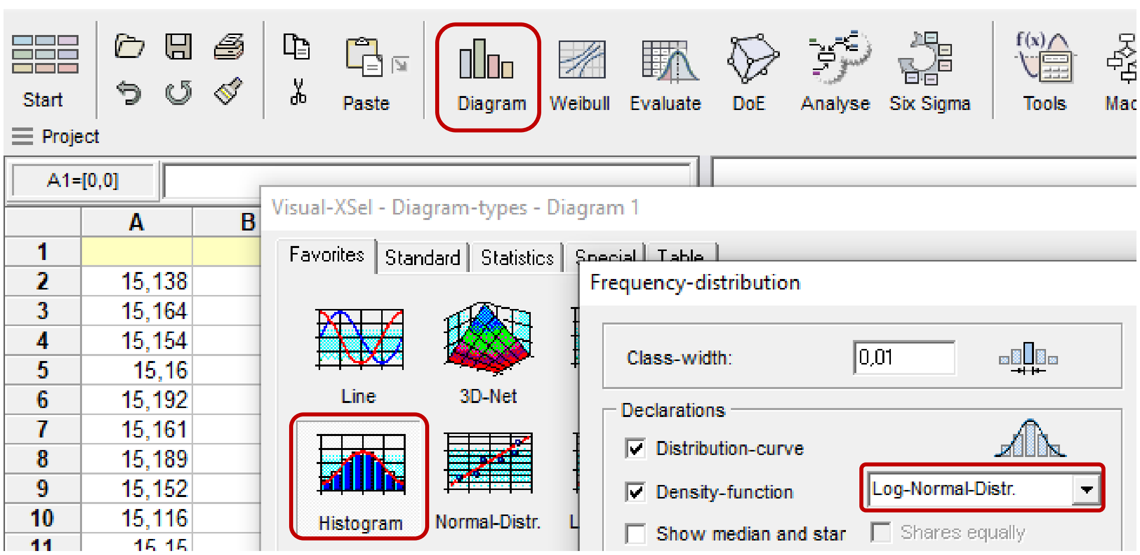


In this case the Lognormal-distribution is the best one. With the same data selection click to the icon *Evaluation* and select the relevant distribution here…

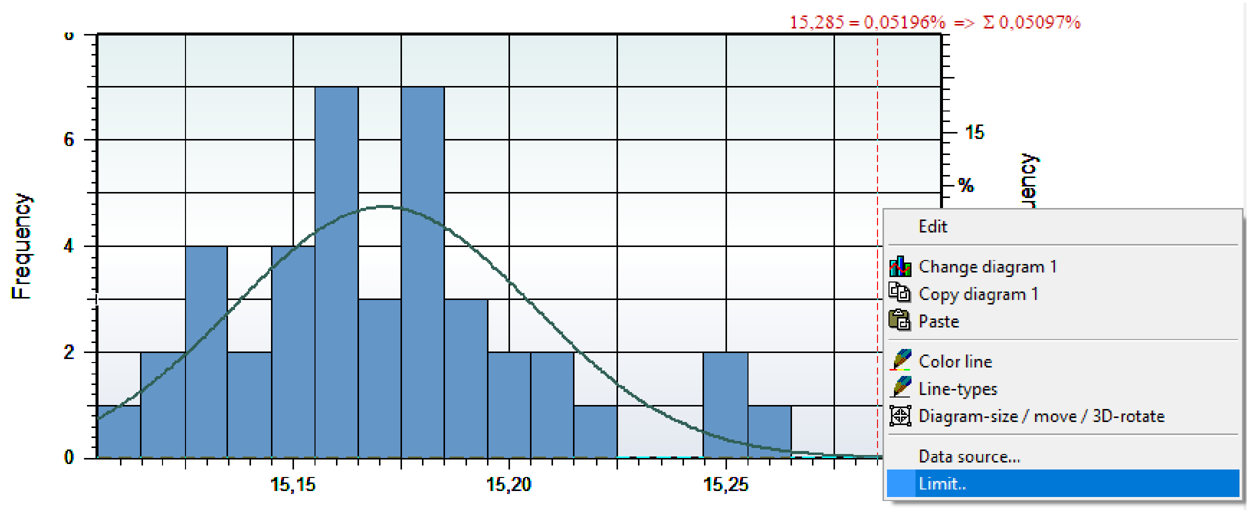


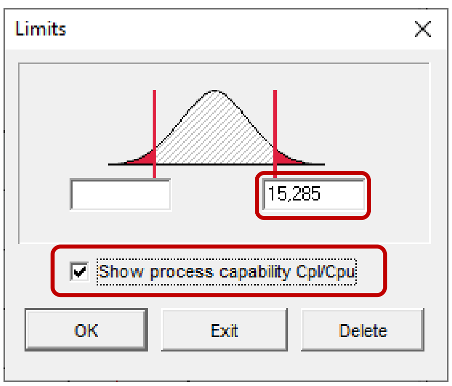


An alternative method is to create a histogram by using the icon *Diagram/ Type.* For this it is the best to copy the data and use it in a new instance of Visual-Xsel (File / New).



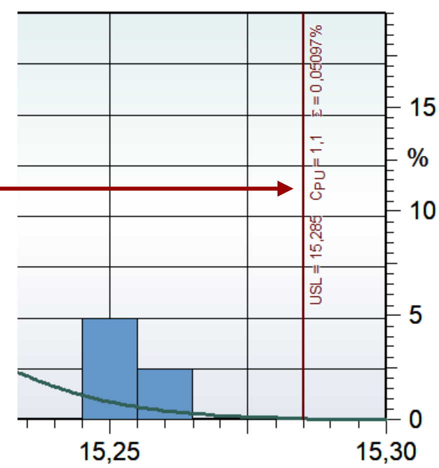
Go with the mouse in the axis area where an upper limit has to be defined and use the right mouse button.





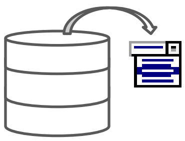
If the mouse position is not really exact, the value can be set directly. Set the option “Show process capability…”.

After that the limit with C_{pu} is shown on the right side. Here we have an unsufficient value - C_{pu} <1.33

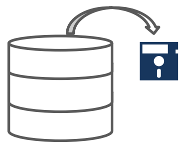


Automatically Analysis from a data base

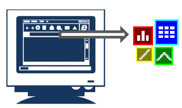
Process Capability Analyses can be started automatically from a data base. The steps are shown in principle:



Select a data set for one attribute to analyse



Export data set as AQDEF file *.*qdf* (complete path)



Start Visual-Xsel 17.0 with the wanted Analysis and the file name, e.g.

Execute* ⇨ *C:\Apps\XSel_17\XSel17.exe \CPKFile.qdf

- *Execute*: specific command to start applications e.g. Windows comm. *CMD*
- *C:\Apps\XSel_17\XSel17.exe*: Location of XSel17
- space
- *\CPK*: Order for Process Capability Analysis*
- *File.qdf*: the exported AQDEF file

possible commands:

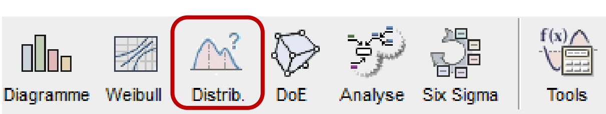
\MSA1 : Measurement_System_Analysis_Type1_CgCgk_.vxg
\MSA4 : Meassurement_System_Analyse_ANOVA_MSA4_.vxg
\VDA5 : Meassurement_System_Analyse_ANOVA_VDA5_.vxg

\CMK : Machine_Capability_Analysis_CmCmk_.vxg
\CPK : Process_Capability_Analysis_CpCpk_.vxg
\CF1 : Process_Capability_Folded_Normal_Distribution_Type_1_.vxg
\CF2 : Process_Capability_Folded_Normal_Distribution_Type_2_.vxg
\CPW : Process_Capability_Weibull_.vxg
\CPL : Process_Capability_Lognormal_.vxg
\PPK : Process_Performance_Analysis_PpPpk_.vxg

\CCX : Control_Chart_x_.vxg
\CCS : Control_Chart_x_s_.vxg

* between order and file name no space is allowed

If the process capability is used and the data is not normal distributed check the best one with this icon:



Select the distribution with the best p-value or choose the wanted via the right table and push OK to open an to add the new template in the project.