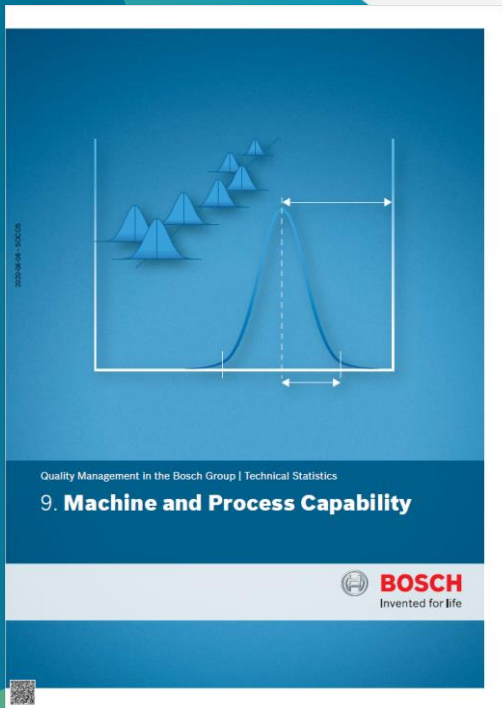

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Machine and Process Capability

Bosch Booklet 9 – 5th edition 2019

Notes:

Preliminary Note

- The basis of booklet 9 (2019) and this seminar is the ISO 22514 series of standards,
  - [ISO 22514-3] ISO 22514-3:2008:02, Statistical methods in process management – Capability and performance, Part 3: Machine performance studies for measured data on discrete parts
  - [ISO 22514-2] DIN ISO 22514-2:2015-06, Statistical methods in process management – Capability and performance – Teil 2: Process capability and performance of time-dependent process models (ISO 22514-2:2013)
  - [ISO 22514-6] ISO 22514-6:2013-02, Statistical methods in process management – Capability and performance, Part 6: Process capability statistics for characteristics following a multivariate normal distribution
- Terms used are mainly taken from
  - [ISO 22514-1] DIN ISO 22514-1:2016-06, Statistical methods in process management - Capability and performance - Part 1: General principles and concepts (ISO 22514-1:2014)
  - [ISO 3534-1] DIN ISO 3534-1:2009-10, Statistics - Vocabulary and symbols - Part 1: General statistical terms and terms used in probability (ISO 3534-1:2006)
  - [ISO 3534-2] DIN ISO 3534-2:2013-12, Statistics - Vocabulary and symbols - Part 2: Applied statistics (ISO 3534-2:2006)
  - [ISO 9000] DIN EN ISO 9000:2015-11, Quality management systems - Fundamentals and vocabulary (ISO 9000:2015)
  - [VIM] Internationales Wörterbuch der Metrologie (VIM), Deutsch-Englische Fassung ISO/IEC-Leitfaden 99:2007, 4. Auflage (2012), Herausgeber DIN Deutsches Institut für Normung, Beuth Verlag Berlin Wien Zürich, ISBN 978-3-410-23472-3

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Notes:

Process

Definition:

This document deals exclusively with **production** and **assembly processes**. A process is understood as a series of activities or procedures in which raw materials or pre-machined parts or components are further processed to generate a finished product.

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Notes:

Capability/Performance Indices

Definition:

Quantitative measures for evaluating capability include the machine and process capability or process performance indices. These must achieve or surpass the specified minimum values.

The minimum requirements given in this manual for capability and performance indices are valid at the time of publication (edition date). In case of conflict, the requirements of CDQ0301 are binding and take precedence over this manual. Higher minimum requirements for process capability or performance may exist for special characteristics or may be specified internally on a product-by-product basis.

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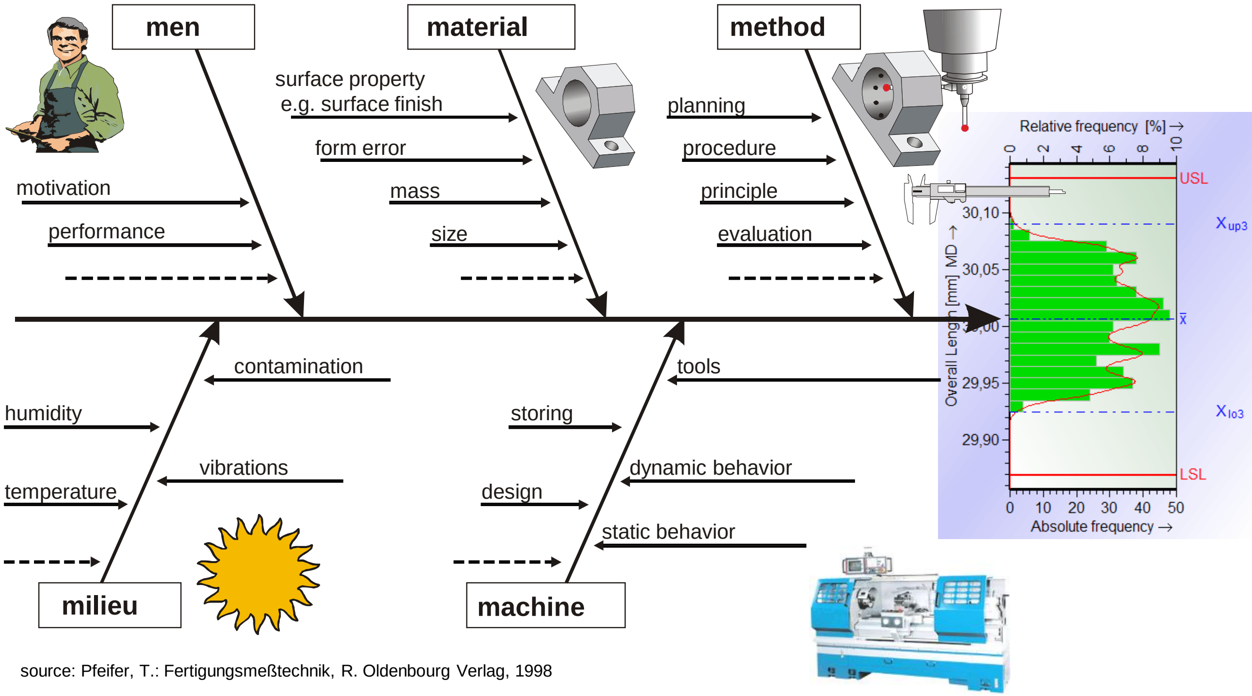
Notes:

Notes:

What are the reasons for process variation?



source: Pfeifer, T.: Fertigungsmeßtechnik, R. Oldenbourg Verlag, 1998

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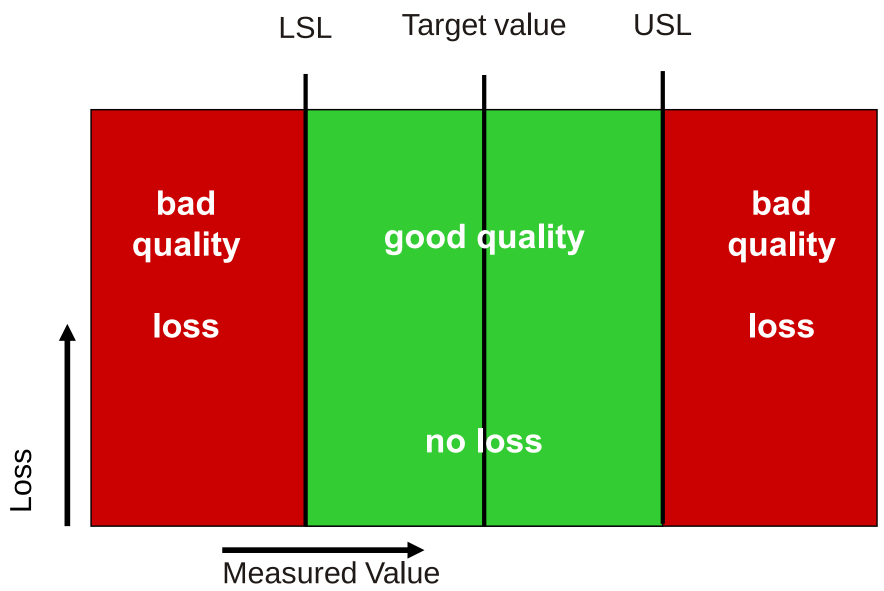
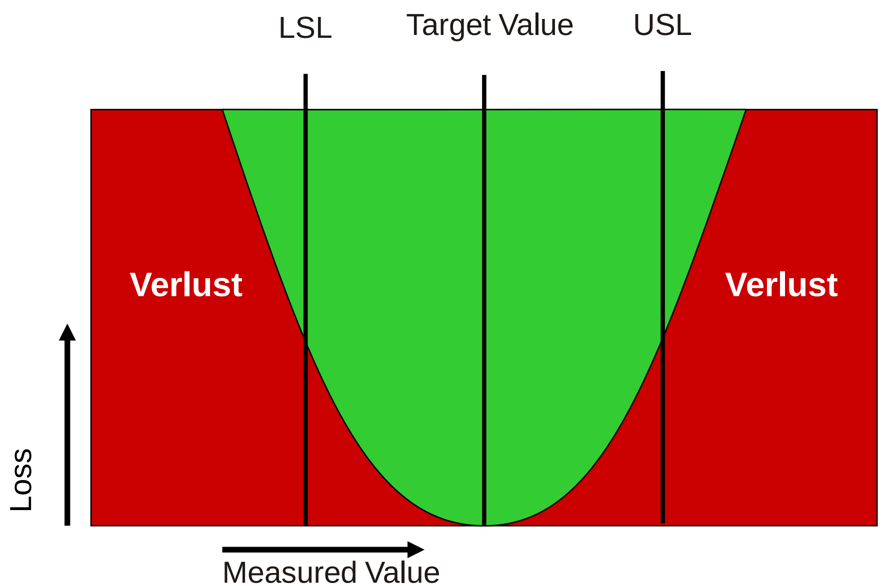
Process Evaluation Philosophies



~~The tolerance belongs to the production!~~

Notes:

Process Evaluation Philosophies



Taguchi loss function

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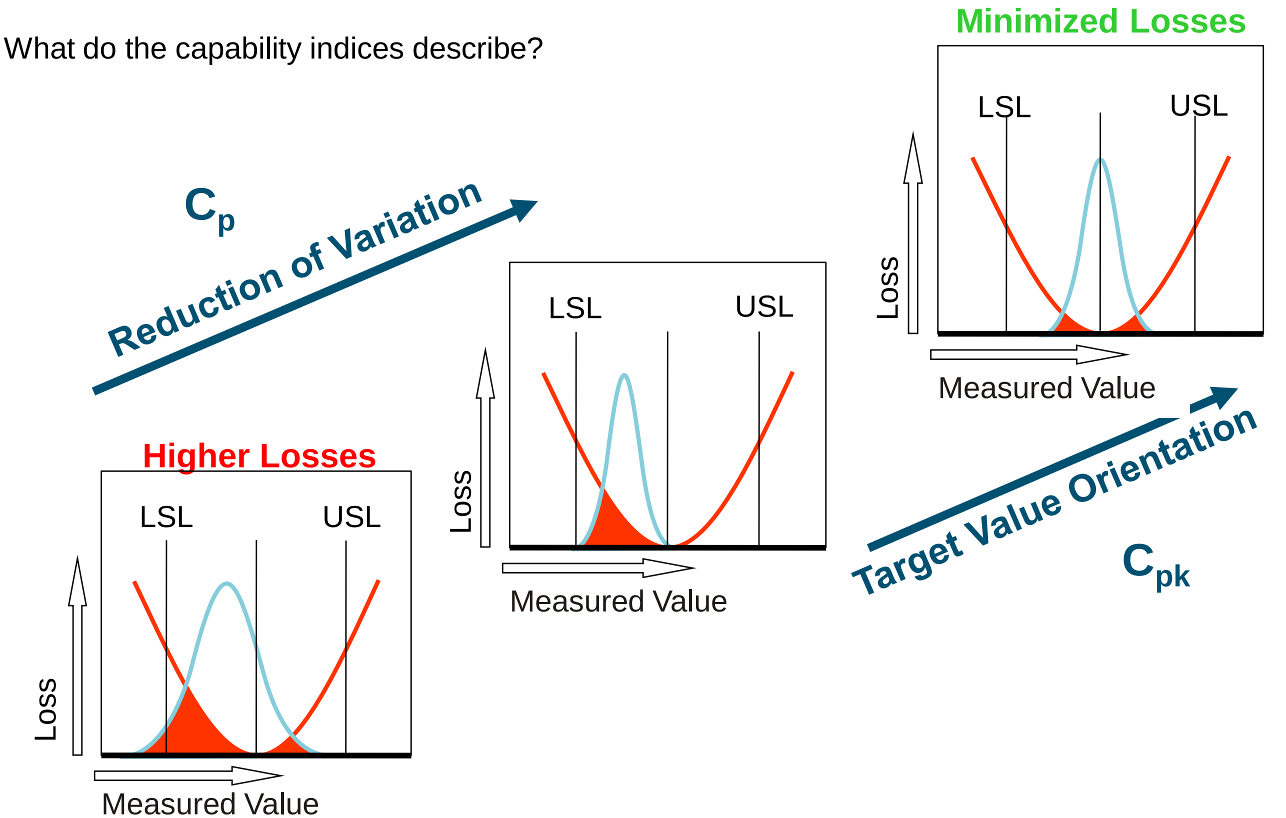
Notes:

Process Evaluation Philosophies

- What do the capability indices describe?



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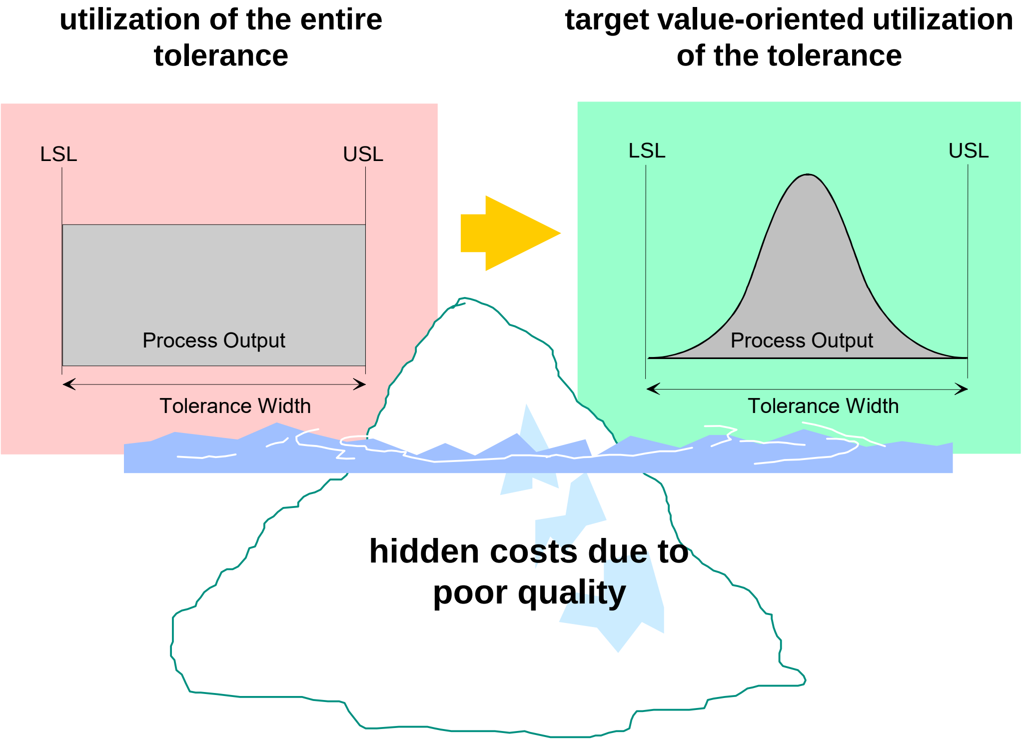
Notes:

What follows from this?



Notes:

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Capability Study/SPC Procedure

- **Selection of Process and Characteristic**
  - Which product characteristics are important or relevant to the customer? Which ones are available for these specifications?
- **Measurability** of product characteristics
  - Are the measurement systems/measuring devices suitable to record the measurement values of the product characteristics with an appropriate degree of accuracy? (**measurement system analysis**)
- **Feasibility** of products
  - Are the machines/facilities suitable to produce products of appropriate quality? (**machine capability**)

Booklet 9

- **Producibility** of products
  - Are we able to ensure the product quality over a longer period? (**process capability**)
- **Controllability** of processes
  - Do we know the process behavior sufficiently well in order to be able to react to changes in an appropriate way? (**quality control charts**)

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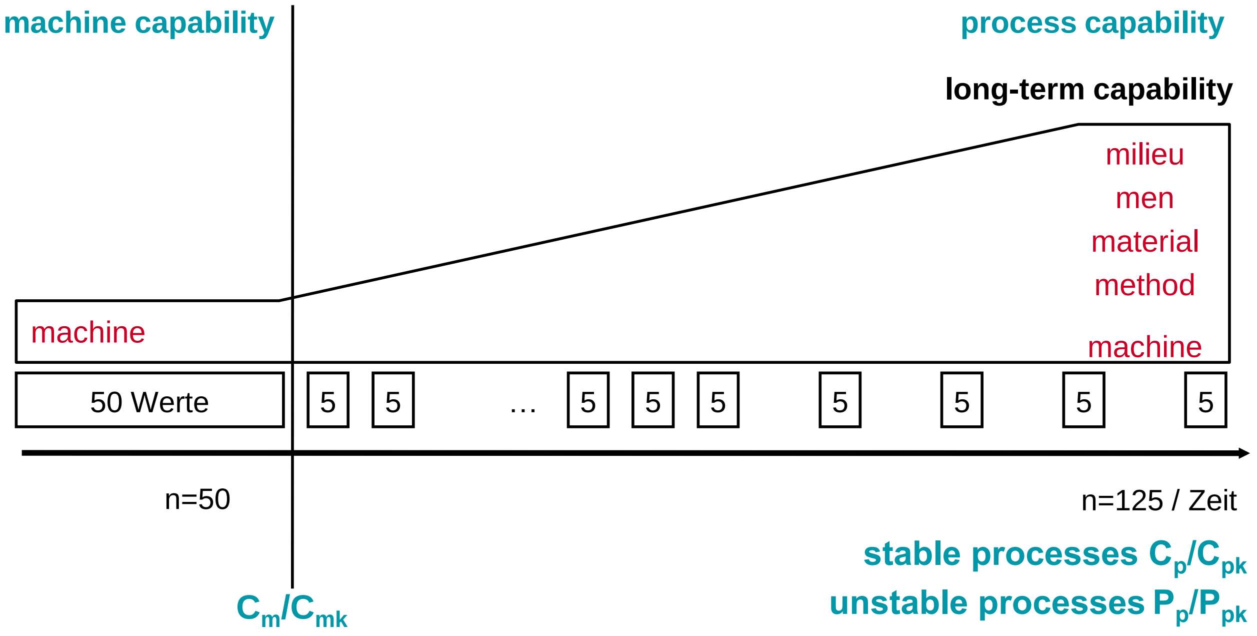
Notes:

Notes:

Qualification Levels according to Booklet 9



target values: 1.67 1.33

(2.0 in case of short acceptance)

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Capability indices according to Bosch booklets 9 and 10 (2019)

- Capability of measurement and test processs C_g/C_{gk}, $\%GRR$
- Machine capability C_m/C_{mk}
- Short-term capability/performance of a production process C_{p-ST}/C_{pk-ST} and P_{p-ST}/P_{pk-ST}
  - Usually only by special agreement (e.g. customer requirement)
    - Parts should, if possible, not be taken from the process in consecutive order (All influencing variables should be able to act on the process)
    - however, contrary to long-term capability parts can be taken successively if too few parts are produced in total
    - Sample parts (products produced in the trial run) are admissible upon agreement with customers or when no serial parts are available
    - Calculation formulas correspond C_p/C_{pk} or P_p/P_{pk} according to booklet 9
    - Sample size n ≥ 125 and all target values $C_{xx-ST}/P_{xx-ST} \geq 1.67$
    - Reports must be marked as short-term studies
    - qs-STAT, Module PC, Evaluation Strategy “Bosch 2018 (Short Term / Kurzzeit)”
- Long-term capability/performance of a production process C_p/C_{pk} und P_p/P_{pk}

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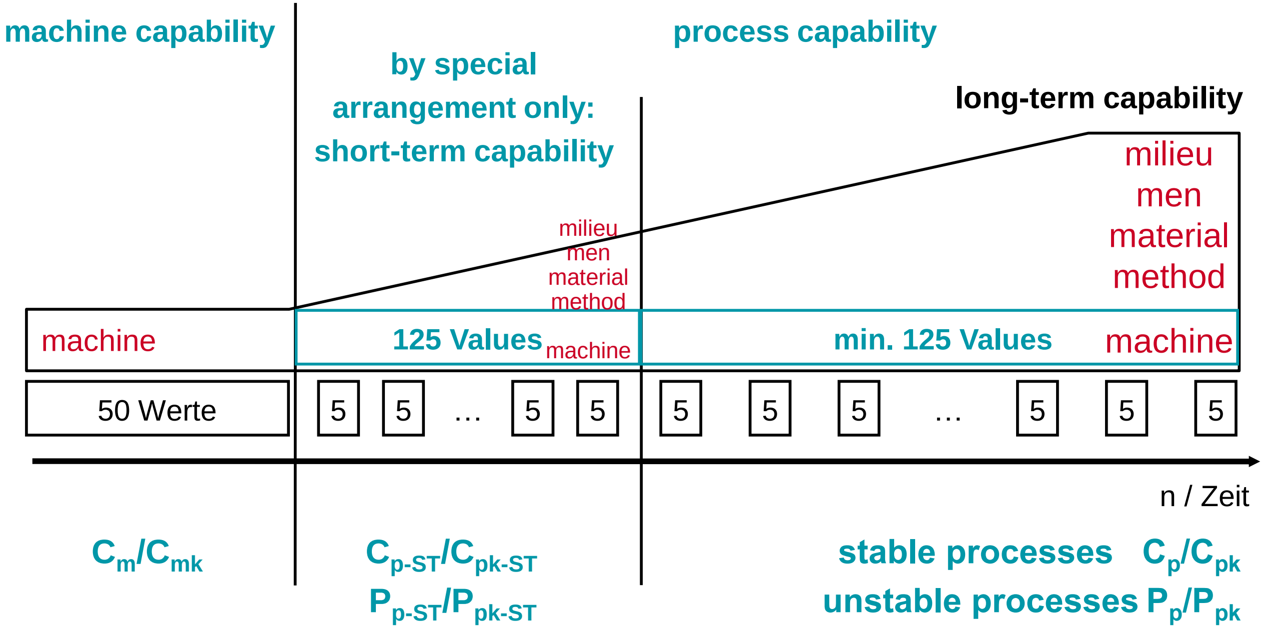
Notes:

Notes:

Qualification levels according to Bosch Booklet 9



target values: 1.67 1.67 1.33

(2.0 in case of short acceptance)

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Notes:

Selection of Characteristics

- SPC features are mainly
  - Customer-relevant characteristics (e.g. special customer requirements)
  - Function-relevant characteristics (e.g. requirements from development and construction)
  - Production-critical characteristics (e.g. knowledge from production preparation)
  - Inspection-critical characteristics e.g. Requirements from test planning and metrology)
  - Safety-critical features (Legislators, Legal Requirements, Guidelines)
- Definition of "quality characteristic" according to DIN EN ISO 9000:2015 (3.10.2)
  - „inherent characteristic of an object related to a requirement“
  - An object is an entity, an item, something perceivable or conceivable (Examples: Product, service, process, person, …)
  - I.e. a quality characteristic can be a product or process characteristic
- Determination
  - by interdisciplinary team (Inspection planning, Simultaneous Engineering, …
  - based on D-FMEA, P-FMEA, CT-Matrix, VoC, …

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Procedure

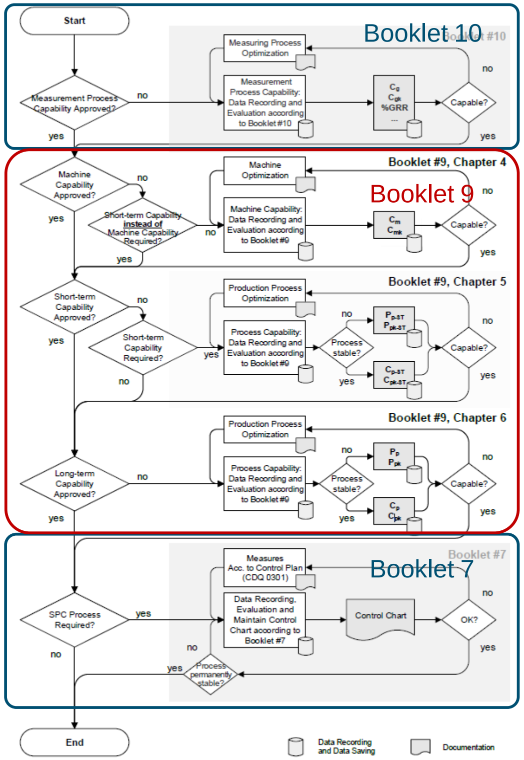
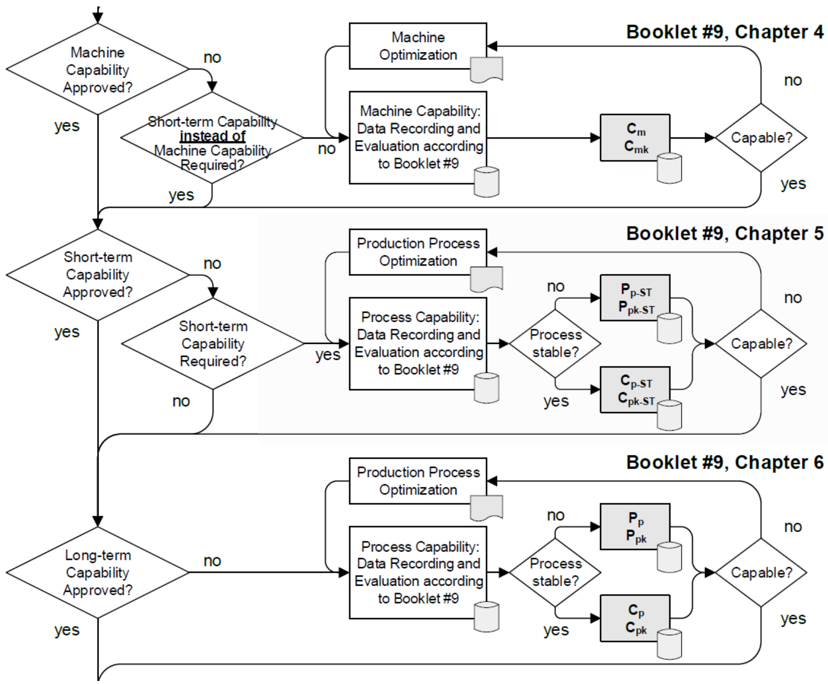


Figure 1: Operational sequence of capability analyses and process monitoring



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Notes:

Notes:

Machine Capability Study procedure

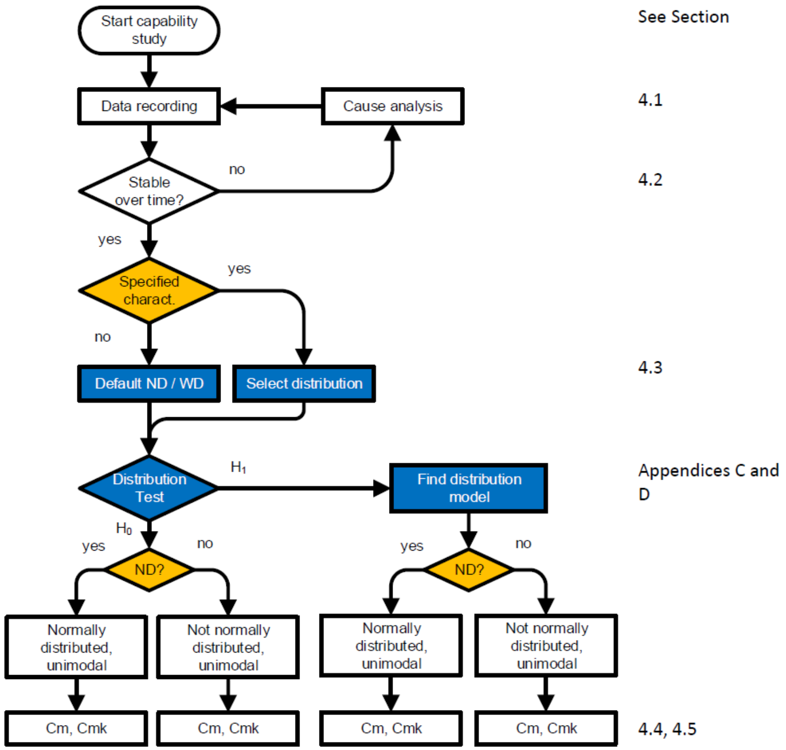

Figure 2: Flowchart depicting the procedure of a machine capability study

Process Capability Study procedure

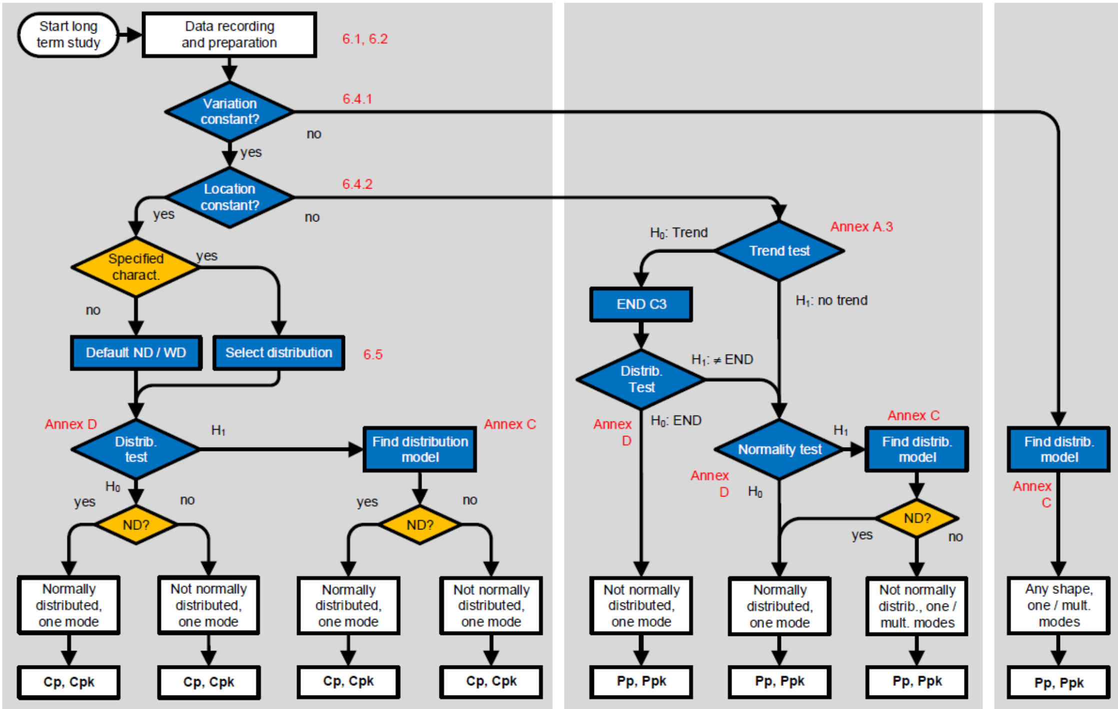

Figure 4: Procedure of a long-term study for manufacturing process capability

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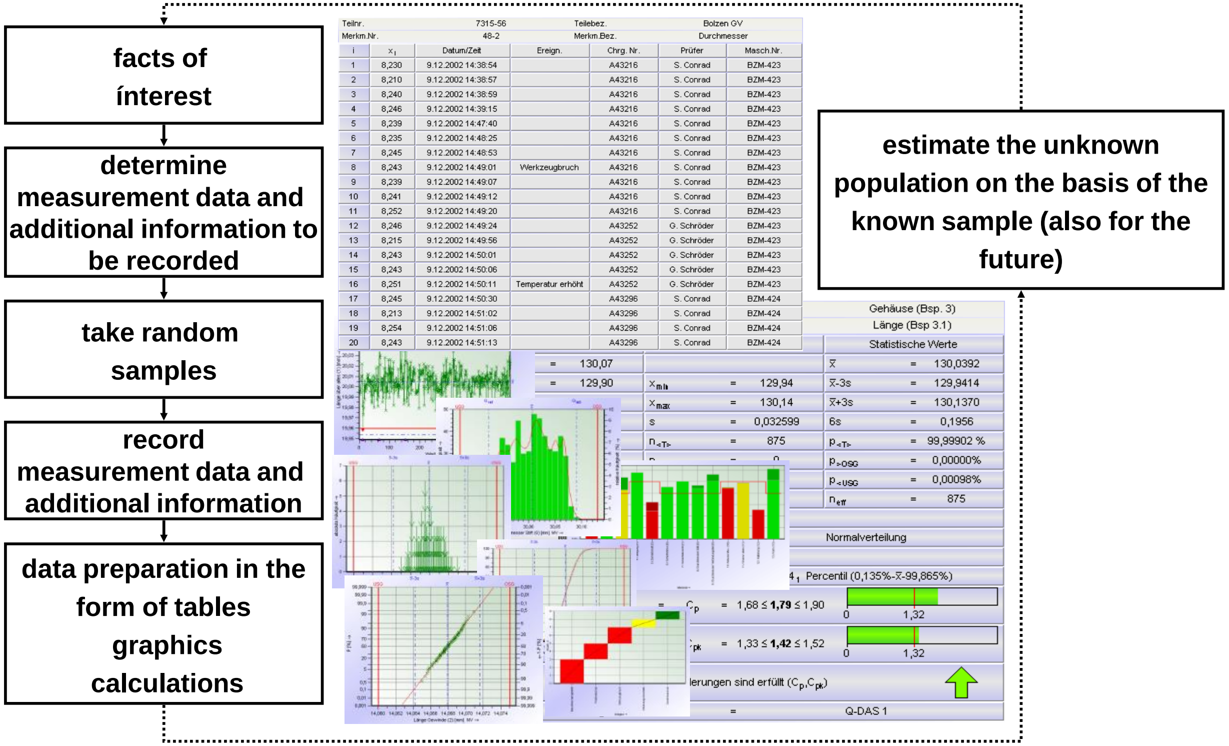
Notes:

Notes:

Schematic Illustration



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Machine Capability Study

- Quote booklet 9 :
  „The study of the machine capability is a short-term study. The aim is to detect and evaluate exclusively machine-related influences on the manufacturing process — and possibly understand. "

- Application:
  - at the manufacturer's in case of a new acquisition, purchase decision
  - for acceptance after the installation at the destination
  - when starting a production process that produces new products

Notes:

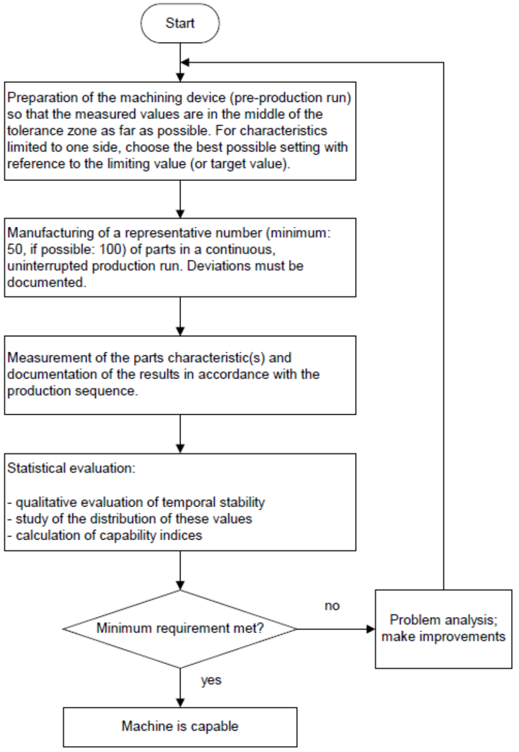
Machine Capability Study

- Prepare machine
  - Adjust tolerance center or target value (in case of unilateral characteristics)

➔ Produce representative number of parts
  - minimum 50,
  - as possible 100,
  - continuous and
  - uninterrupted production flow

- Measurements according to the respective production sequence

- Statistical evaluation
  - qualitative evaluation of stability over time
  - inspection of the distribution
  - calculation of capability indices



Notes:

Machine Capability Study - Acceptance procedure

- Organizational preparations
  - inter-divisional acceptance team
    - quality
    - production
    - construction
    - metrology and test engineering
  - knowledge of statistical methods
  - determination of analysis methods and tools (guidelines und software)
    - guidelines and directives
    - software and evaluation strategy
    - particular formalities (process owner/project leader)
  - involvement of suppliers and subcontractors

Notes:

Machine Capability Study - Acceptance procedure

- Planning of the machine acceptance
  - schedule, tasks and responsibilities
  - number of required parts
    - provision of parts by the customer
    - quality of raw materials/rough machining
  - confirmation of the test plan
    - determination of the types and classes of characteristics
  - special regulation
    - particular characteristics, special target values
  - verification of error prevention measures/process conditions
    - error proofing/process monitoring
    - fault simulation/rejection logic
  - determination of the sampling

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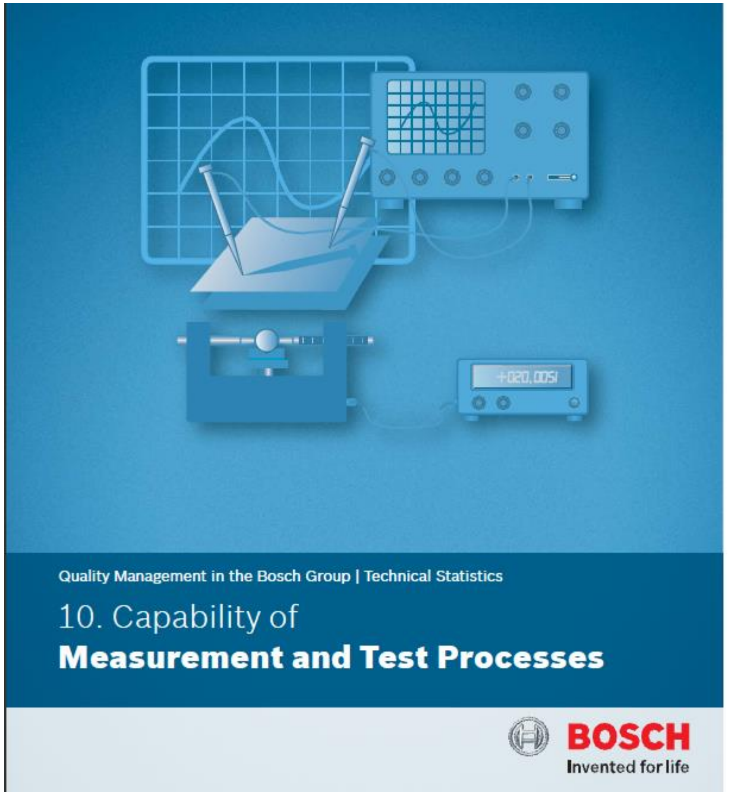
Notes:

Machine Capability Study - Acceptance procedure

- Capability of measurement and test processes
  - try to use the measuring and test equipment that will also be applied in the process
  - discuss alternate measuring devices with customers
  - capability study according to booklet 10 or
    - AIAG Quality Core Tool MSA
    - VDA Volume 5
    - customer guidelines



Notes:

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Notes:

Influence of the Measurement Process Variation

$$\sigma^2{}_{observed} = \sigma^2{}_{actual} + \sigma^2{}_{measuring\ system}$$

observed process variation

actual process variation

variation of the measuring system

Impacts on process capability!

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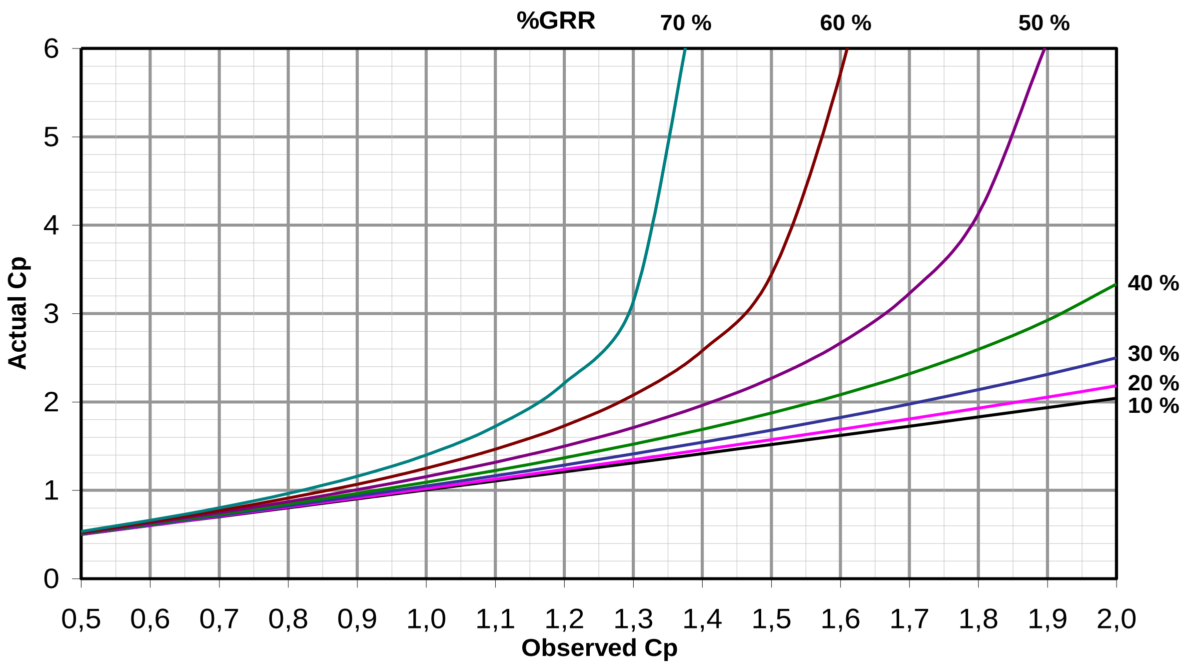
Influence of the Measurement Process Variation



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Notes:

Please note: It is not justifiable to extrapolate from an observed capability index to an "actual capability index" via an assumed dispersion of the measurement system ...

Machine Capability Study - Acceptance procedure

- Machine preparation and adjustment
  - durability test
    - running time from 8 to 24 hours, same parameters as in production
    - reliability of mechanics and controls
    - error proofing, test error display and diagnostics procedure
    - provide documentation
  - handling of parts
    - take, transport, drop parts
    - highlight 5 parts, inspect alignment, locating and clamping points and transport supports
    - check for damages
  - cold start test
    - initial situation is the same as at the end of a shift
    - produce at least 5 parts in the cold start phase of the machine

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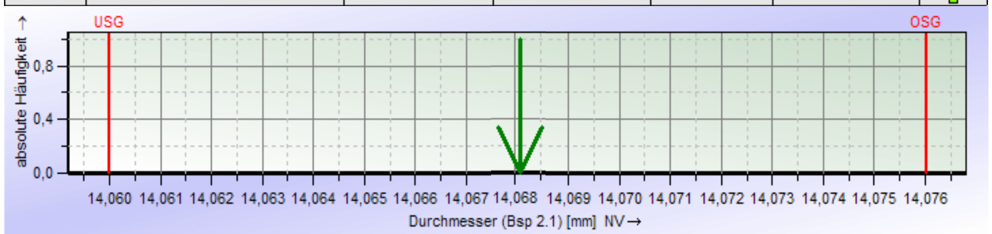
Notes:

Machine Capability Study - Acceptance procedure

- Machine preparation and adjustment (continued)
  - trial run test in order to adjust the machine
    - 1 part/ 5 parts test (exemplary)

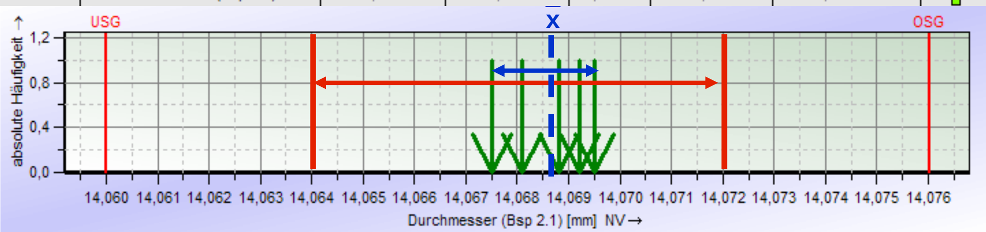
Bosch 2018

Merkm.Nr.	Std. Bez.	USG	OSG	x	x-Tm	
2.1	Durchmesser (Bsp 2.1)	14,0600	14,0760	14,0681	0,0001000	⇧



value within 100% T

Merkm.Nr.	Std. Bez.	USG	OSG	$\bar{x}$	R/T	$\bar{x}$-Tm	
2.1	Durchmesser (Bsp 2.1)	14,0600	14,0760	14,06862(	12,50%	0,000620	⇧



average within and range less than 50% T

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Notes:

Machine Capability Study – Machining of Parts

- Machine at operating state temperature
- Set to working parameters

- Parts can clearly be identified and are recorded in machining sequence
- Continuous run
- Number of parts: typically 100, at least 50

- Transport of pallets
  - test all pallets for dimensions
  - selection of samples for machine acceptance

- Each station is treated like a separate machine

- Machining centers in combination with tool holders/pallets
  - optimization strategy (number of parts)

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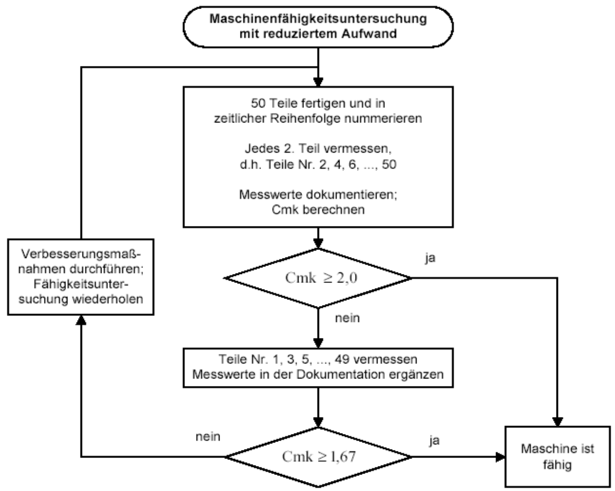
Notes:

Notes:

Machine capability with reduced effort

- Special case for …
  - … very complex measurements, associated with exceptionally high costs
  - … destructive tests
- Reduced sample size → reduced reliability of statements
- Software (qs-STAT®, „Bosch 2018“) automatically adjusts limit value
- For manual evaluation 2-step procedure
  - Manufacture 50 parts, measure every 2nd part calculate capability index, requirement $C_{mk} \geq 2{,}0$
  - If limit value not reached, measure remaining parts and calculate capability index, requirement $C_{mk} \geq 1{,}67$



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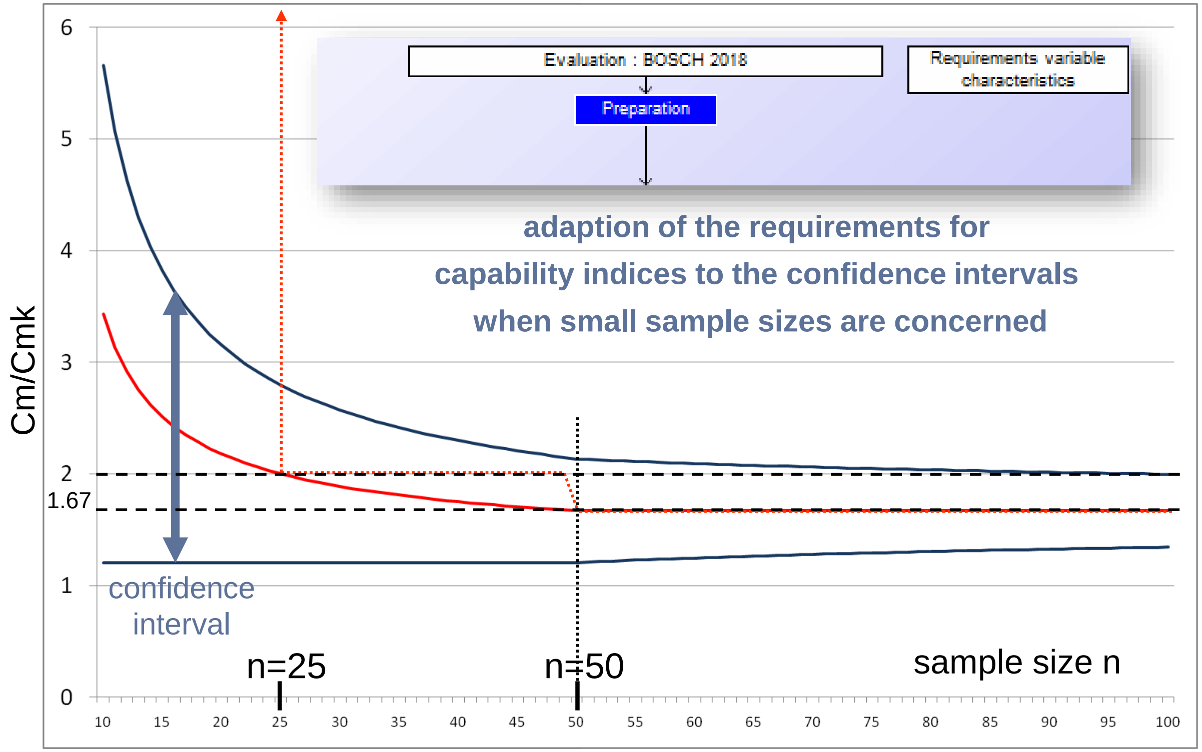
Notes:

Adaption of Capability Indices in Machine Capability Study



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Process capability study (long-term)

- Quote booklet 9 :
  - „ The process capability is the result of a long-term study”
  - In addition to the pure machine-related influences, all possible influences should be detected which affect the manufacturing process for a longer operating time.
  - These disturbances can be summarized in categories by the superordinate concepts
    man,
    machine,
    material,
    method and
    milieu,
    often abbreviated by 5M.

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Notes:

Process capability study (long-term)

- Procedure according to booklet 9 (quotations)

- “The study requires a
  - representative number of the production quantity,
  - but at least 125 non-selected parts (for example, m = 25 samples each with sample size n = 5)
  - over a sufficiently long period of time,
  - so that all possible expected influences can have an effect on the process.

- “… the characteristics are measured on each part and the results for each part are documented according to the production sequence.

- „Data evaluation in the context of process capability analysis requires that the data set to be analyzed does not contain any “outliers”. “

- Evaluation of the process stability
- Evaluation of the statistical distribution
- Calculation of capability and performance indices

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Notes:

Process capability (short-term)

- Differences to long-term process capability according to booklet 9

- Reason:
  - series rump-up(neither sufficient product parts available nor sufficiently long period)
  - „Initial Process Capability“ [AIAG PPAP]
  - „Preliminary process capability“ [VDA-4]

- Short-term screening may differ from long-term screening
  - Sampling over a shorter period of time in shorter intervals, if necessary immediately one after the other.
  - Number of parts: less than the 125 parts required for the long-term study
  - Target values for capability and performance indices:
    - more than 125 parts: increased limit value 1.67
    - less than 125 parts target value raised depending on number of parts as in long-term study with reduced quantities
  - Designation of the characteristic values: Capability indices are marked with C_{p-ST} and C_{pk-ST}, performance indices with P_{p-ST} and P_{pk-ST}.
  - The evaluation of the data is carried out in the same way as for the long-term study.

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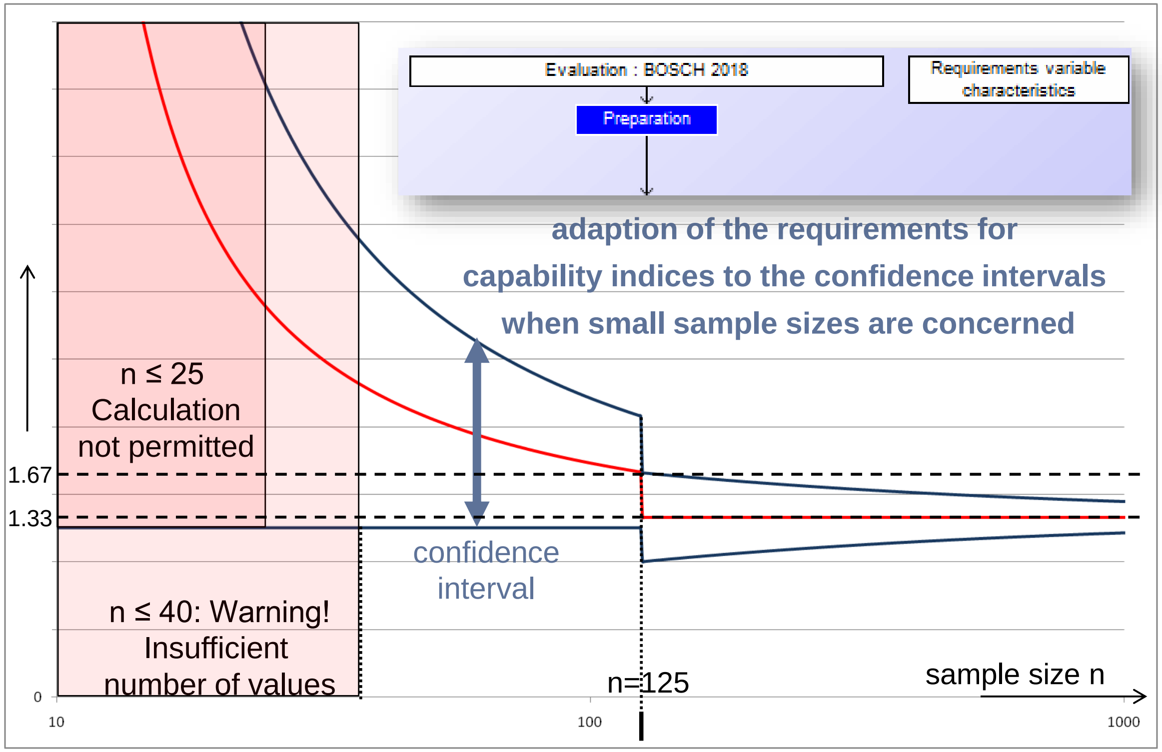
Notes:

Adaption of Capability Indices in Process Capability Study



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Notes:

Stability assessment

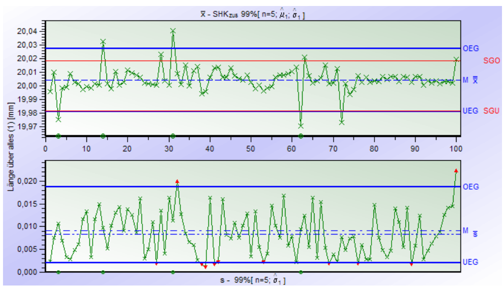
- How can you check for process stability?

With analysis of variance

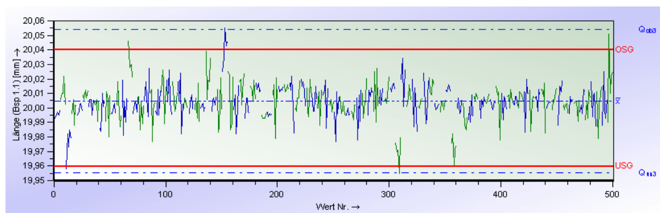
ANOVA			
Streuung innerhalb der Stichproben	=	s_I^2	0,000093687
Zusätzliche Streuung zwischen den Stichproben	=	s_A^2	0,000064438
Anteil der zusätzlichen Streuung zwischen den Stichproben	=	s_A^2/s_{ges}^2	0,41
H_0	Varianz zwischen den Stichproben ist Null		
H_1	Varianz zwischen den Stichproben ist NICHT null.		

Testniveau	kritische Werte unten	kritische Werte oben	Prüfgröße
$\alpha = 5$ %	---	1,28	4,43899***
$\alpha = 1$ %	---	1,42	
$\alpha = 0,1$ %	---	1,59	
Testergebnis	Nullhypothese wird zum Niveau $\alpha \leq 0,1\%$ verworfen		

With quality control card



With single value plots



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Notes:

Data analysis

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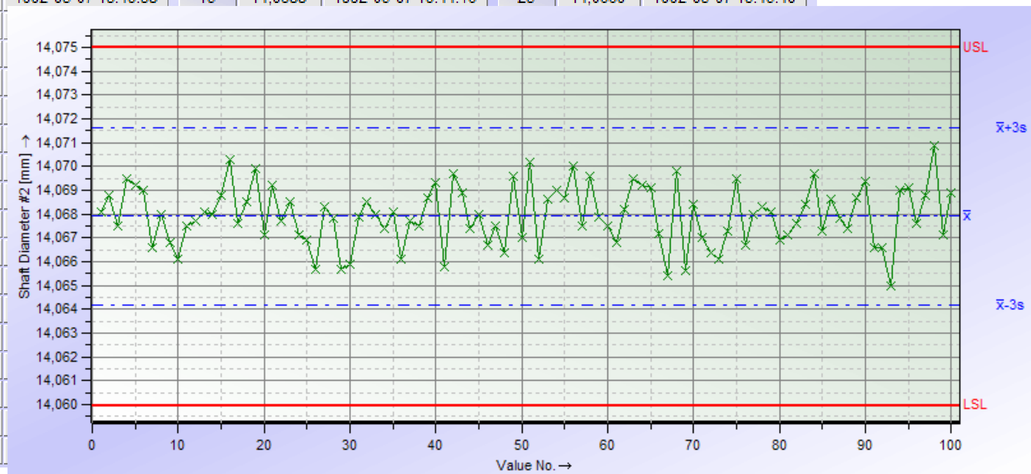
Notes:

Value Chart

Part no.	1	Part descr.	Test 2
Char.No.	1	Char.Descr.	Shaft Diameter #2

i	x_i	Date/Time	i	x_i	Date/Time	i	x_i	Date/Time
1	14,0681	1992-05-07 13:43:08	11	14,0675	1992-05-07 13:44:10	21	14,0692	1992-05-07 13:45:30
2	14,0688	1992-05-07 13:43:28	12	14,0677	1992-05-07 13:44:12	22	14,0677	1992-05-07 13:45:32
3	14,0675	1992-05-07 13:43:32	13	14,0681	1992-05-07 13:44:14	23	14,0685	1992-05-07 13:45:36
4	14,0695	1992-05-07 13:43:36	14	14,0680	1992-05-07 13:44:14	24	14,0671	1992-05-07 13:45:38
5	14,0692	1992-05-07 13:43:38	15	14,0688	1992-05-07 13:44:16	25	14,0669	1992-05-07 13:45:40
6	14,0690							
7	14,0666							
8	14,0680							
9	14,0668							
10	14,0661							

i	x_i
31	14,0679
32	14,0685
33	14,0680
34	14,0674
35	14,0681
36	14,0661
37	14,0677
38	14,0675
39	14,0687
40	14,0693



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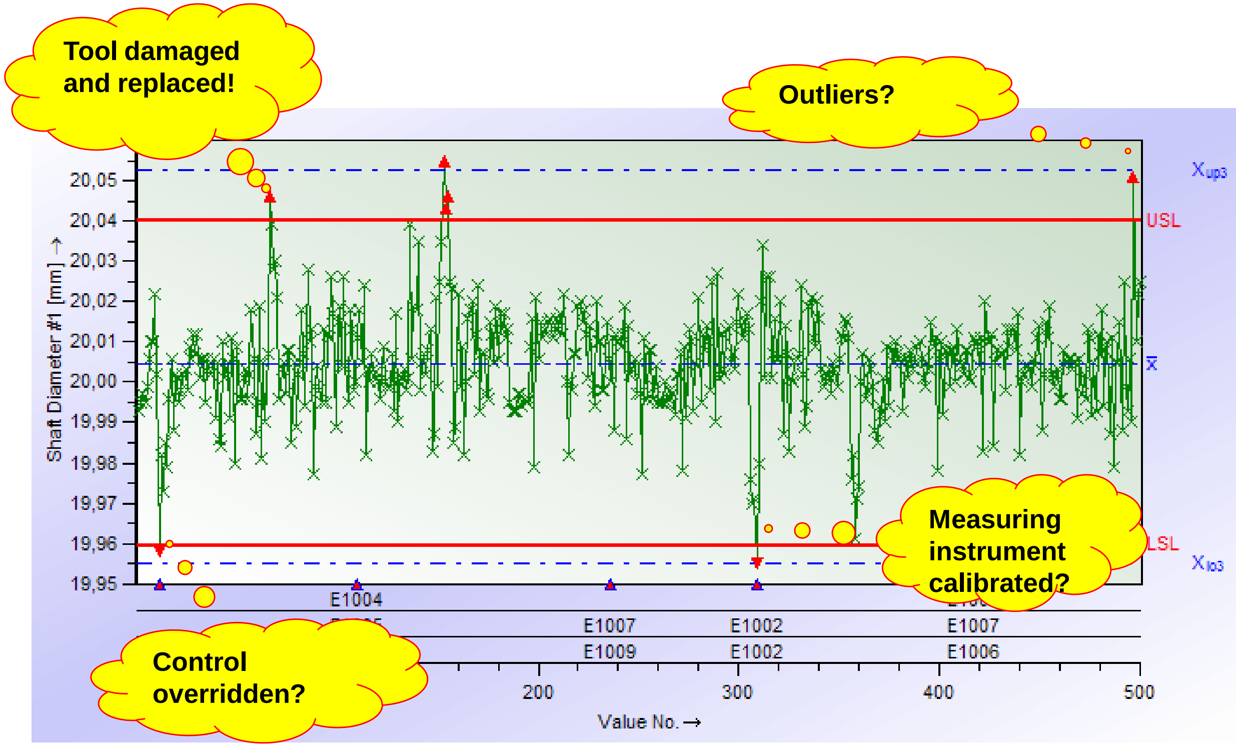
Notes:

Notes:

Is the Process Stable?



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Additional Data

- Date and time of the recording of the measured values
- Inspector, appraiser, operator
- Machine
- Cavity (clamping point / spindle / casting mold ...)
- Measuring and test equipment
- Events, measures, causes
- Batch (part ID number / serial number /...)
- Reworking measures
- Condition of the raw parts
- …

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Notes:

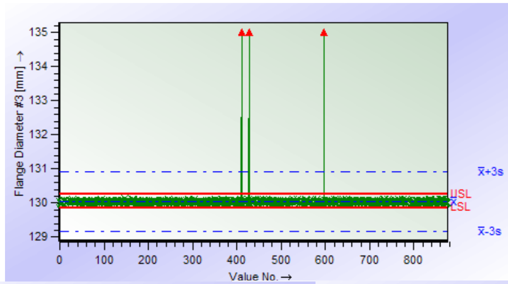
Parameters Affecting the Process

- Machine settings
  - (rotational) speed
  - feed
  - tools
  - cycle times
  - coolant flow/temperature
  - …
- Environment
  - room temperature
  - humidity
  - air pressure
  - building vibrations (location, floor)
  - ...
- Parts-related process parameters
  - semi-finished parts, raw parts
  - condition and quality of the rough-machined parts
  - process warm-up time prior to the sampling
  - ...

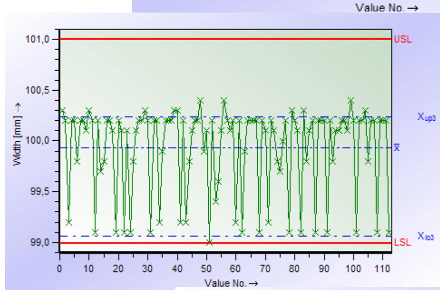
Notes:

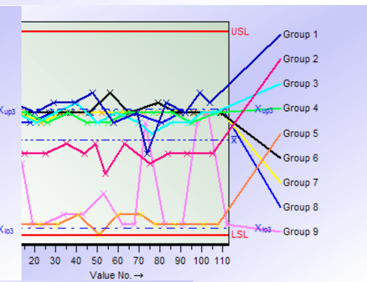
Data quality examples

- Outlier
  - solution: monitor the input with the help of plausibility limits

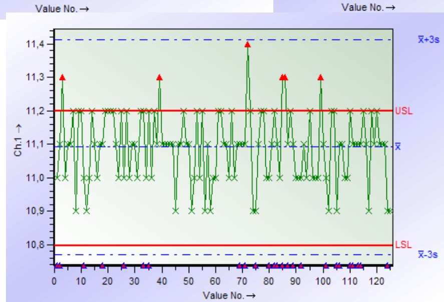


- Blend of different cavities
  - solution: evaluate each cavity separately





- Measuring system – bad resolution
  - solution: make a measurement system analysis



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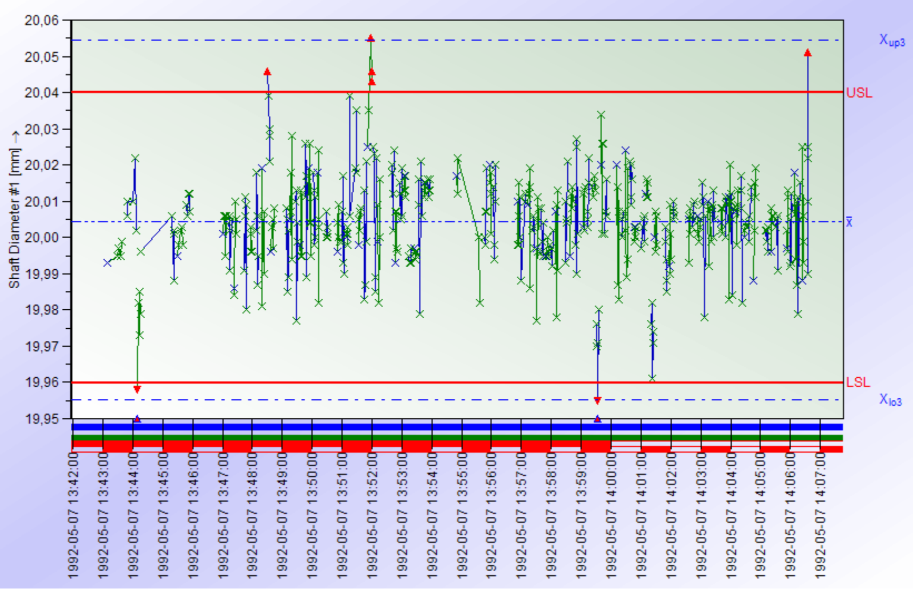
Notes:

Analysis Functionalities

- Axis scale
  - time/date according to ID number
  - batch
  - real-time display
  - machines
  - cavities
  - operators
  - measuring and test equipment



Notes:

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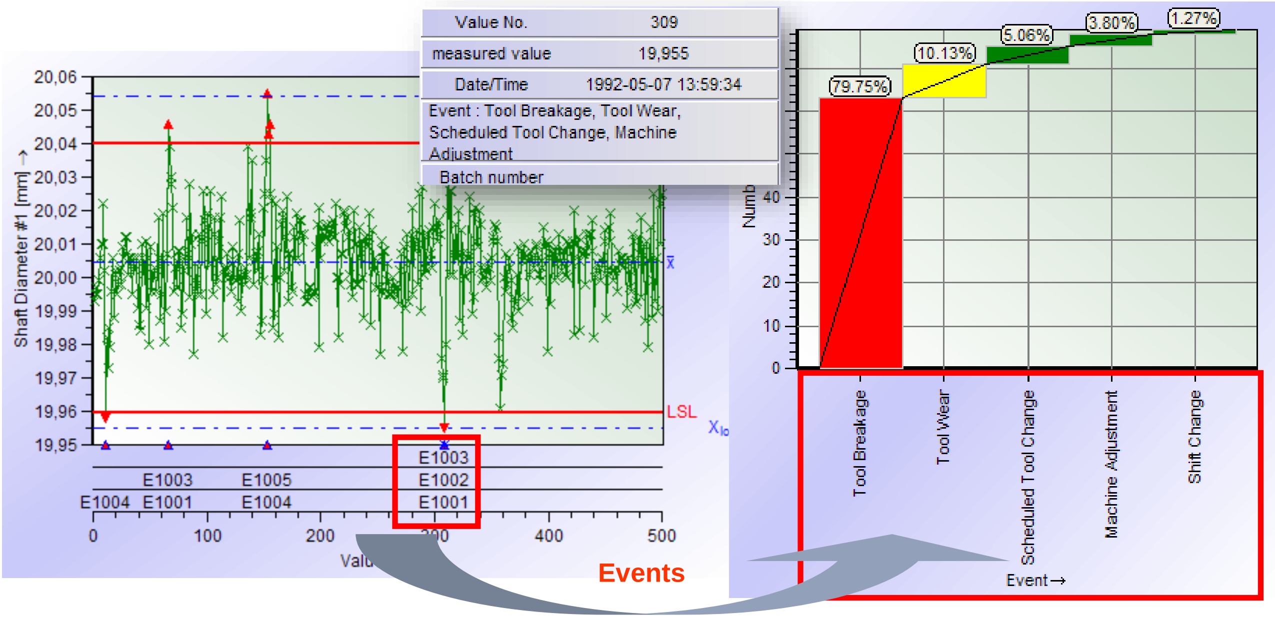
Analysis Functionalities

- Pareto analysis
- Pareto diagrams



Notes:

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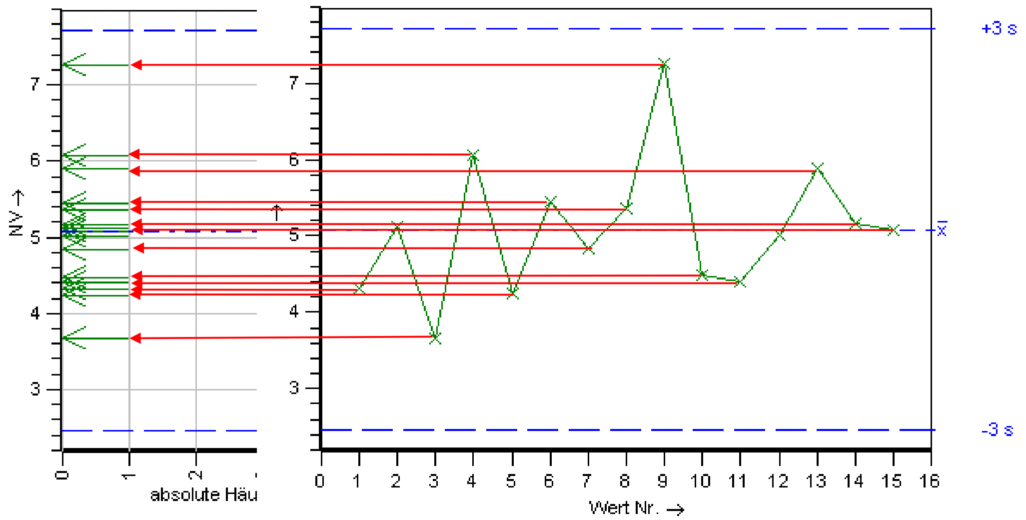
How to Create a Value Plot



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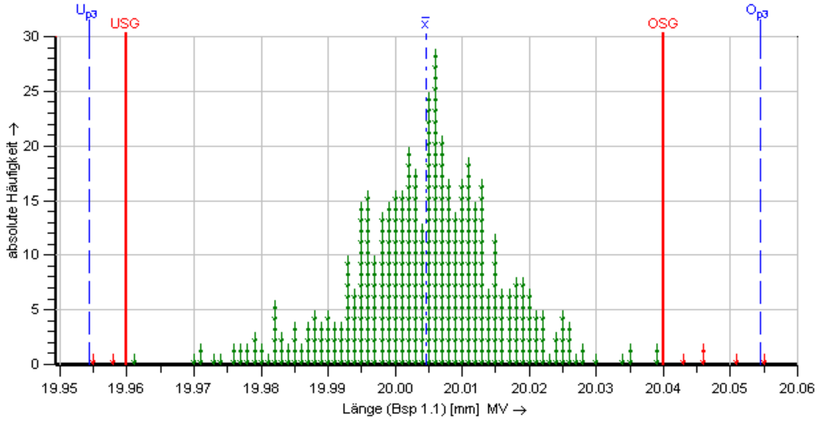
Notes:

Development of a value plot from a value progression.

Analysis Functionalities

- Considerations regarding the value plot:
  - at least 5-7 visible levels
  - at least 20 levels are possible within the tolerance (i.e. $\%RE \leq 5\%$ of the tolerance)
  - no irregularities in the display of the value plot

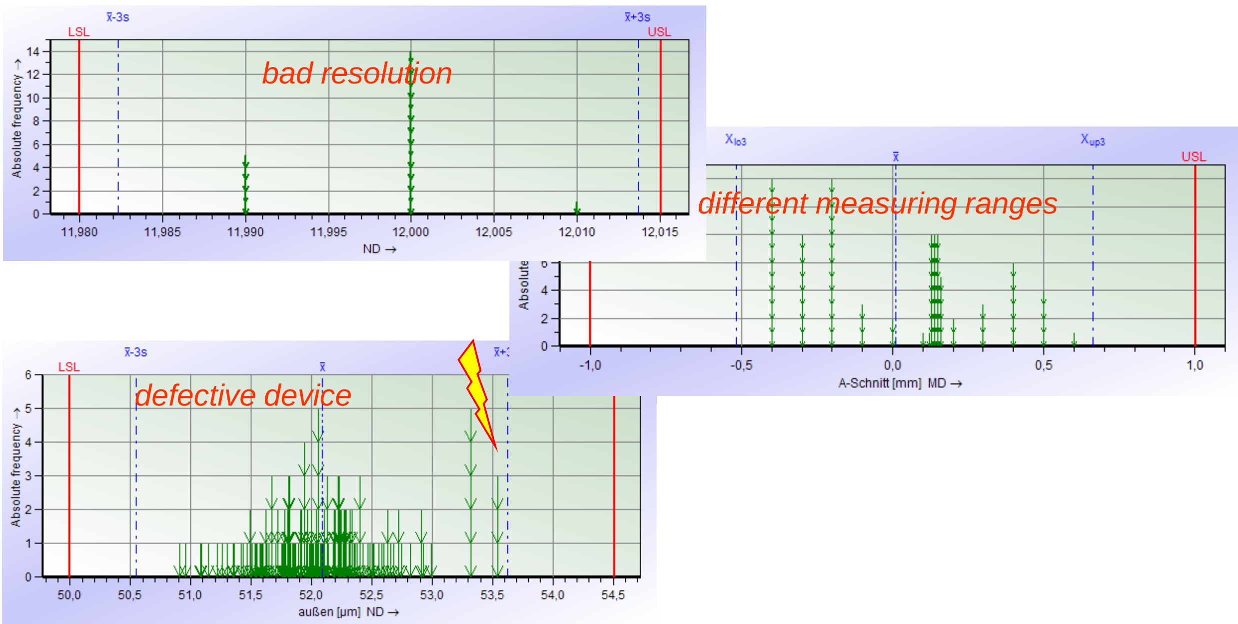


Notes:

The points mentioned above check whether
- sufficient instances have been recorded from which a distribution shape can be derived
- the 5% requirement for the resolution of the display from the measurement system analysis and test process capability is met
- conspicuous features should lead to increased caution with regard to calculated characteristic values

Analysis Functionalities

- Examples of bad data quality in the value plot



Notes:

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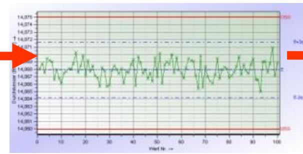
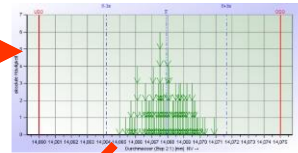
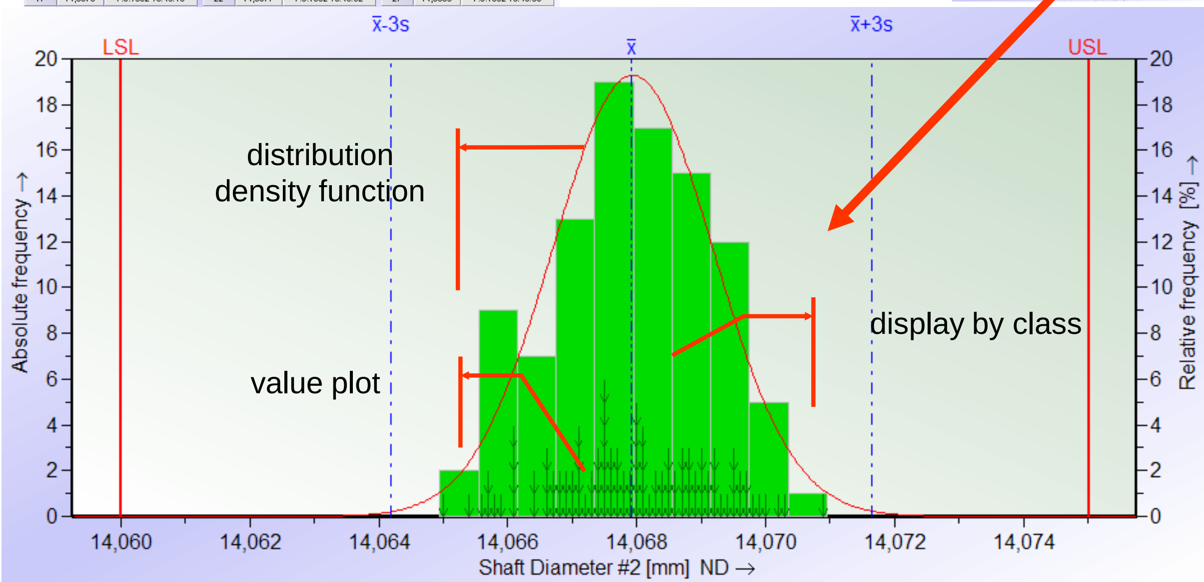
Notes:

Histogram

Teilnr.	2		Teilebez.		Flansch (Bsp 2)			
Merkm.Nr.	2.1		Merkm.Bez.		Durchmesser (Bsp 2.1)			
i	x_i	Datum/Zeit	i	x_i	Datum/Zeit	i	x_i	Datum/Zeit
1	14,0681	7.5.1992 13:43:08	6	14,0690	7.5.1992 13:43:50	11	14,0675	7.5.1992 13:44:10
2	14,0688	7.5.1992 13:43:28	7	14,0666	7.5.1992 13:43:50	12	14,0677	7.5.1992 13:44:12
3	14,0675	7.5.1992 13:43:32	8	14,0680	7.5.1992 13:44:00	13	14,0681	7.5.1992 13:44:14
4	14,0695	7.5.1992 13:43:36	9	14,0668	7.5.1992 13:44:04	14	14,0680	7.5.1992 13:44:14
5	14,0692	7.5.1992 13:43:38	10	14,0661	7.5.1992 13:44:06	15	14,0688	7.5.1992 13:44:16
i	x_i	Datum/Zeit	i	x_i	Datum/Zeit	i	x_i	Datum/Zeit
16	14,0703	7.5.1992 13:44:16	21	14,0692	7.5.1992 13:45:30	26	14,0657	7.5.1992 13:45:48
17	14,0676	7.5.1992 13:45:18	22	14,0677	7.5.1992 13:45:32	27	14,0683	7.5.1992 13:45:50







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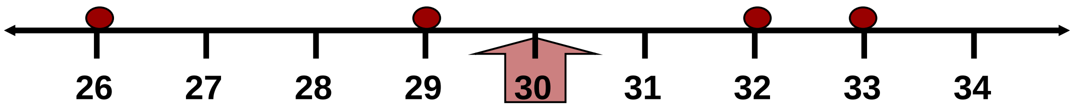
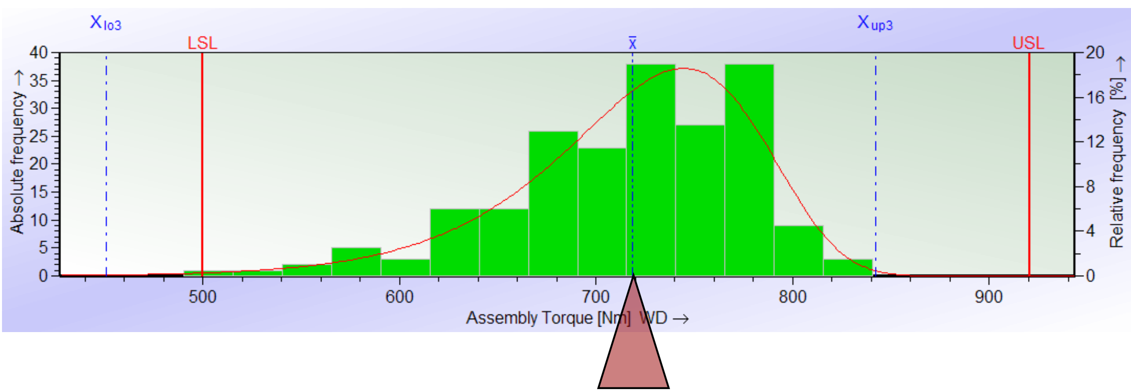
Notes:

Arithmetic Mean

- The arithmetic mean is
- … the sum of all values divided by the number of values.
- … the balance point of the distribution

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$





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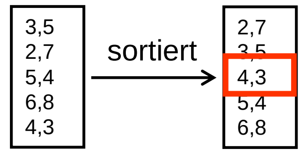
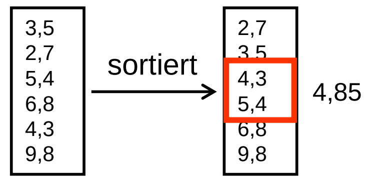
Notes:

Median

- Value in the middle of a series of measured values ordered by the size of the individual values (original list).
- Halves ordered measured value series into two equal parts
- Median for odd number of values: $\tilde{x} = x_{\left(\frac{n+1}{2}\right)}$



- Median for even number of values: $\tilde{x} = \frac{x_{\left(\frac{n}{2}\right)} + x_{\left(\frac{n}{2}+1\right)}}{2}$
  - Arithmetic mean of the two values in the middle



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Notes:

Range

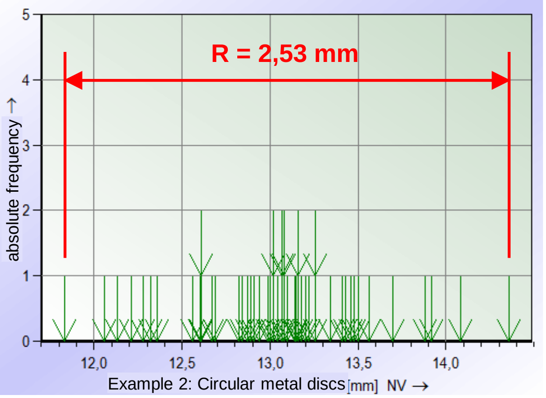
- Distance between largest and smallest value of a value series

$$R = x_{max} - x_{min}$$

- Example 1: Series of numbers
  - Original value list: 3,5 2,7 5,4 6,8 4,3
  - Sorted: 2,7 3,5 4,3 5,4 6,8
  - Range: $R = 6{,}8 - 2{,}7 = 4{,}1$

- Example 2: Circular metal discs

$$x_{min} = 11{,}83\ mm$$
$$x_{max} = 14{,}36\ mm$$
$$R = 14{,}36\ mm - 11{,}83\ mm = 2{,}53\ mm$$



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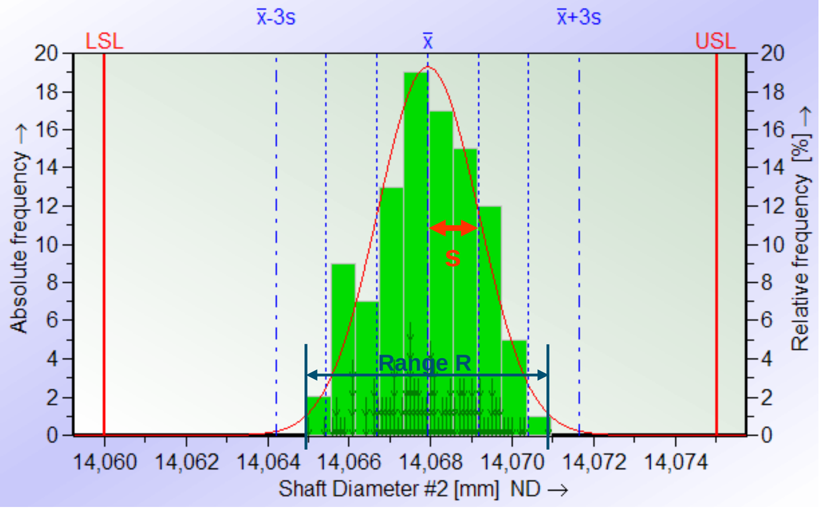
Standard Deviation

- The standard deviation s is
  - the square root of the sum of the squared deviations divided by the degrees of freedom $(n-1)$
  - The distance from the mean to the point of inflection of the normal distribution

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



The standard deviation must not be confused with span or tolerance!

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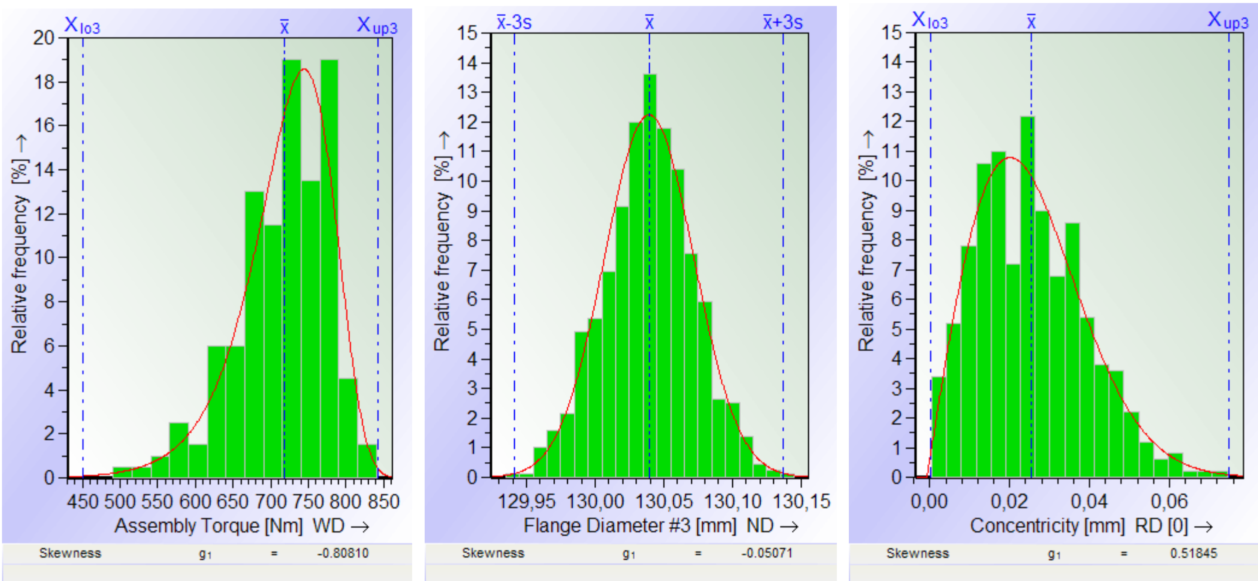
Notes:

Notes:

Skewness

- The skewness g_1 describes the asymmetry of a distribution



$g_1 < 0$ $g_1 = 0$ $g_1 > 0$

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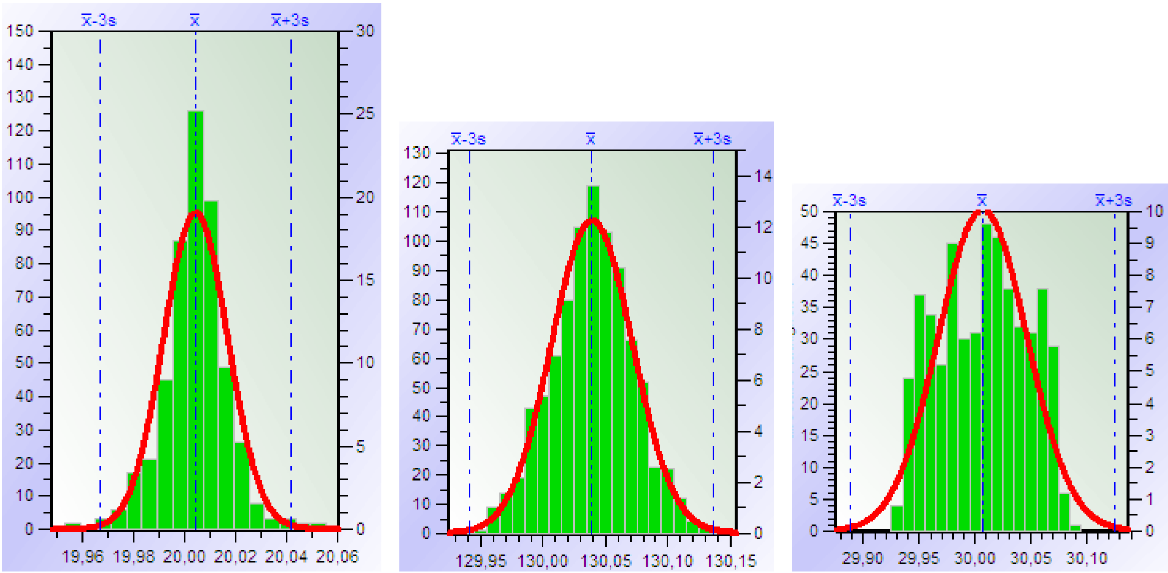
Kurtosis

- The kurtosis b_2 describes the arching/curvature of a distribution



$b_2 > 3$ $b_2 = 3$ $b_2 < 3$

Notes:

Statistics

- Location statistics
  - minimum value/maximum value x_{min}/x_{max}
  - median $\tilde{x}$
  - arithmetic mean $\bar{x} = \frac{1}{n}\sum_i x_i$
- Variation statistics
  - range $R = x_{max} - x_{min}$
  - standard deviation $s = \sqrt{\frac{1}{n-1}\sum_i (x_i - \bar{x})^2}$
- Form statistics
  - skewness g_1 ($g_1 = 0$ bei Normalverteilung)
  - kurtosis b_2 ($b_2 = 0$ bei Normalverteilung)

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Notes:

Random Variation Range

- Range depends on the sample size

Merkm.Nr.	Merkm.Bez.	$\bar{x}$	s	R (n = 15)	s	R (n = 50)	s	R (n = 500)
1	Ch.1	10,11440	1,13497	R =3,693	0,78494	R =3,631	1,02523	R =6,218
2	Ch.2	10,29747	0,80333	R =2,580	0,90549	R =4,015	1,04538	R =6,236
3	Ch.3	9,91240	1,11886	R =4,175	1,14252	R =4,133	1,01157	R =6,651
4	Ch.4	9,67720	1,04647	R =3,167	0,90887	R =4,465	0,94455	R =5,498
5	Ch.5	10,10580	0,84367	R =2,792	0,78263	R =3,131	1,01174	R =6,468
6	Ch.6	10,03840	1,06180	R =4,230	1,06965	R =5,733	0,94874	R =5,955
7	Ch.7	10,38127	0,95627	R =2,837	0,75918	R =3,478	1,02039	R =5,366
8	Ch.8	10,22133	0,59096	R =2,027	1,04225	R =4,182	0,98857	R =5,294
9	Ch.9	10,04127	1,04759	R =3,301	1,01187	R =5,092	0,99312	R =5,715
10	Ch.10	9,81407	1,00313	R =3,672	1,09971	R =4,756	1,02225	R =5,993

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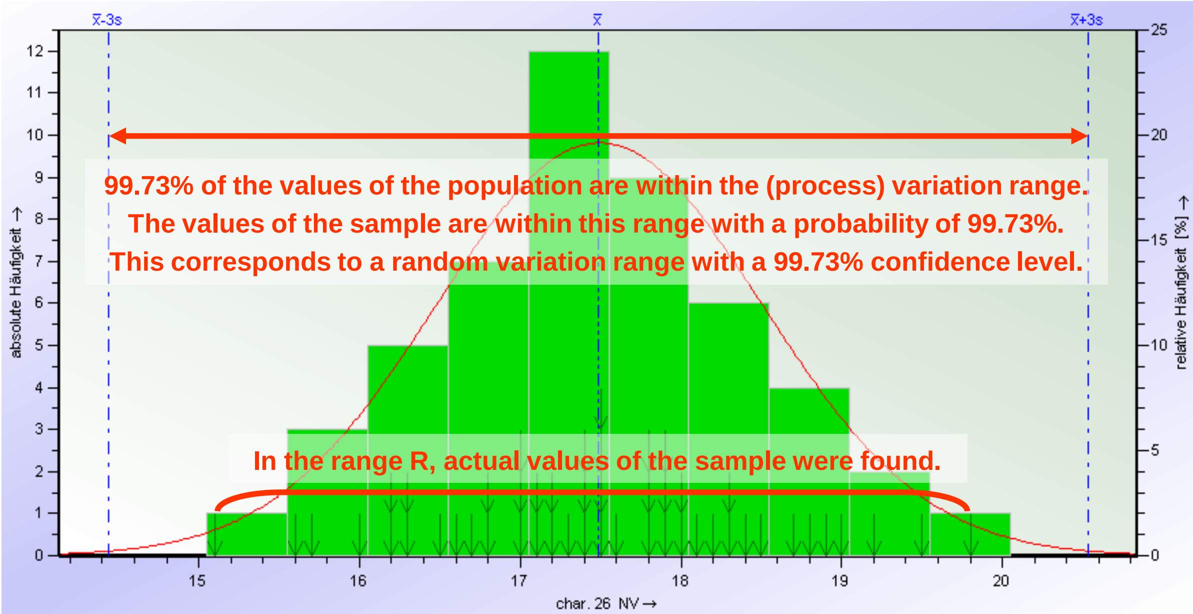
Notes:

Random Variation Range

➔ Range of the measured values correlates with random variation range

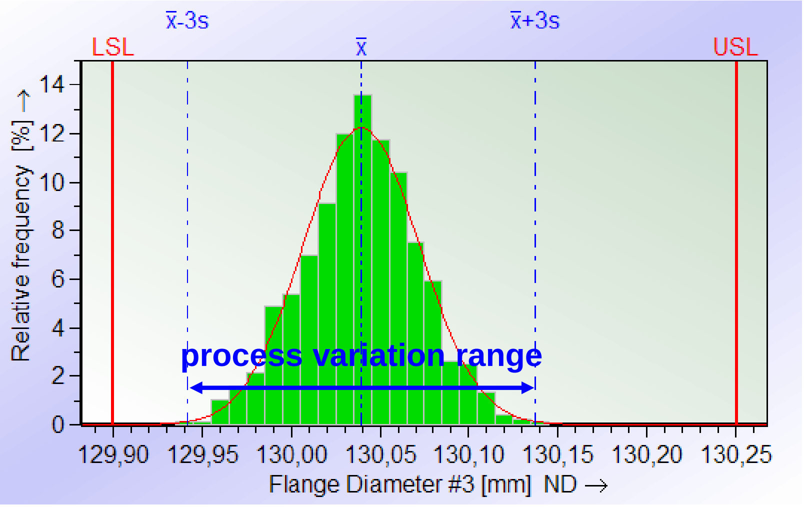


Notes:

Notes:

Capability Index – What is a “Process Variation Range“

- How well does the process conform to the tolerance?
- How wide is the process?
- One possible answer: 99.73% => +/- 3s
- Convention: process variation range = 6s



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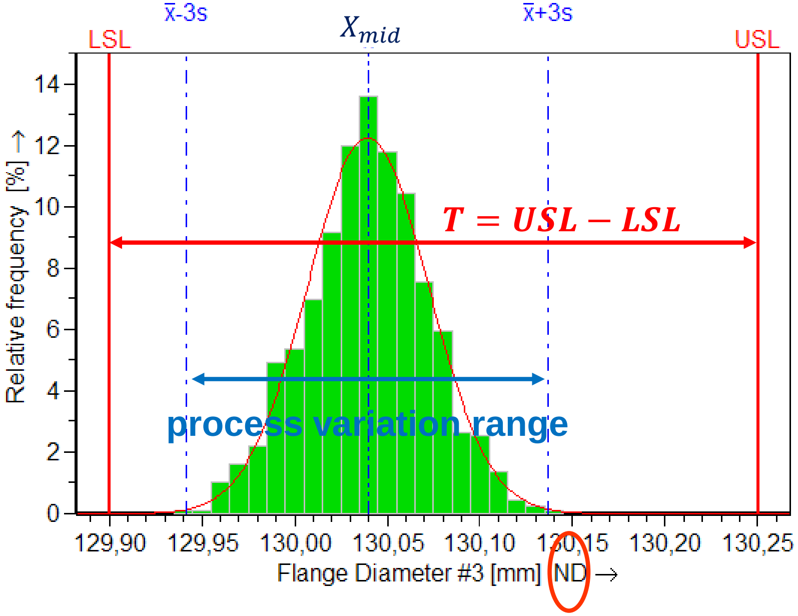
Capability Index C_m, P_p, C_p



$$C_p = \frac{tolerance}{process\ variation\ range} = \frac{USL - LSL}{6s}$$

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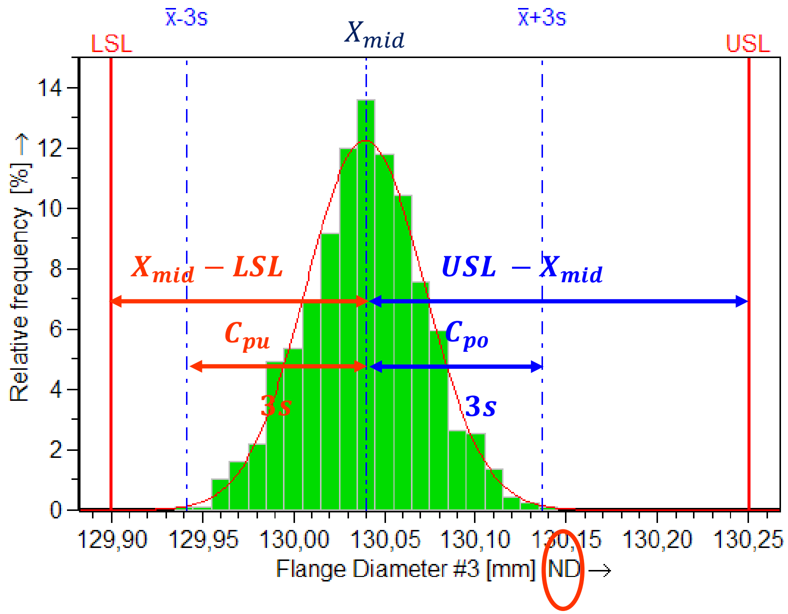
Notes:

Please ALWAYS interpret capabilities as the ratio of two widths, here the tolerance and process spread width.

Notes:

Capability Index C_{mk}, P_{pk}, C_{pk}



$$C_{pu} = \frac{X_{mid} - LSL}{3s}$$

$$C_{po} = \frac{USL - X_{mid}}{3s}$$

$$C_{pk} = min\{C_{pu}, C_{po}\}$$

Normal distribution: $X_{mid} = \bar{x}$

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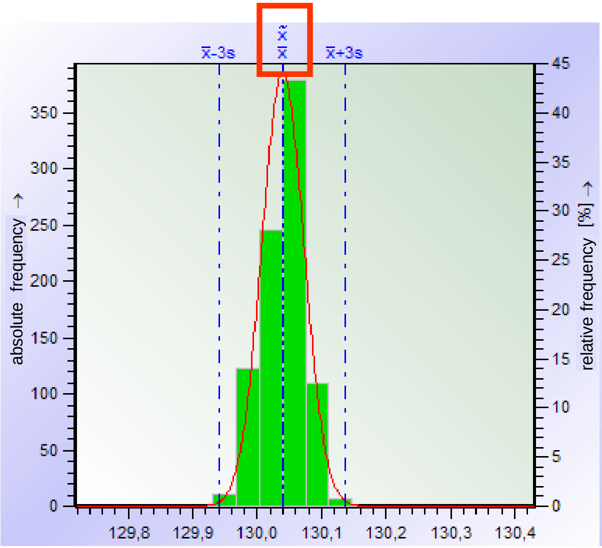
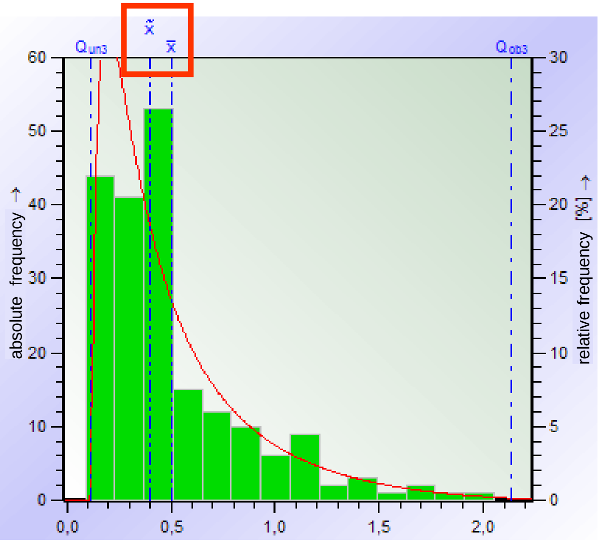
Notes:

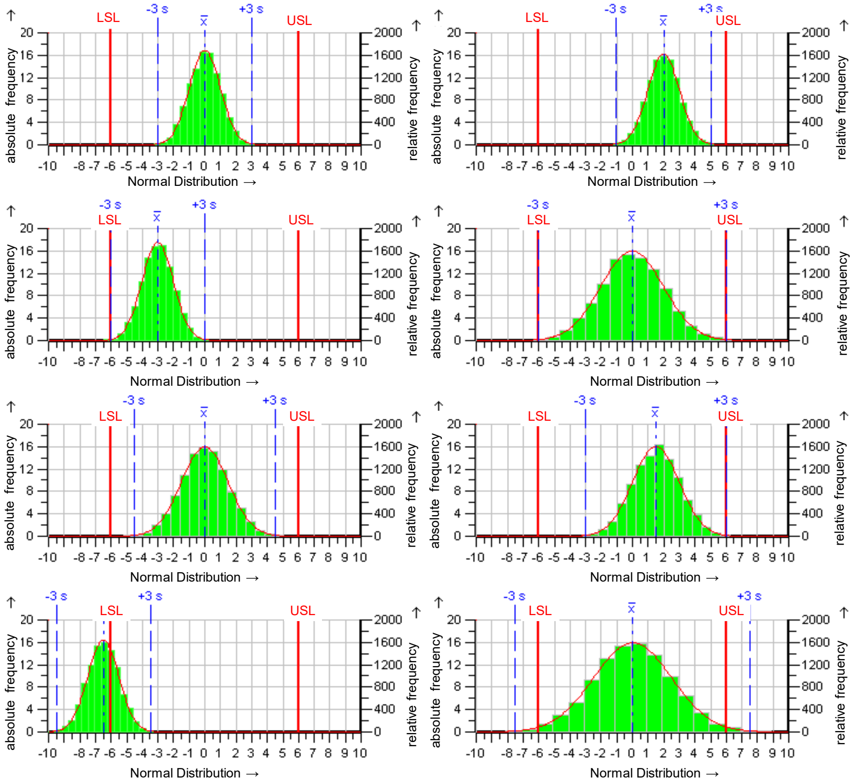
X_{mid} - Median or Average?

- almost identical in normal distributions, but different in skewed distributions
- average is the “balance point“ of the distribution
- median is the central value (50:50) and generally closer to the mode (maximum) in skewed distributions





Please Estimate Capabilities ...



Notes:

Estimate the ability indices Cp and Cpk using the grids

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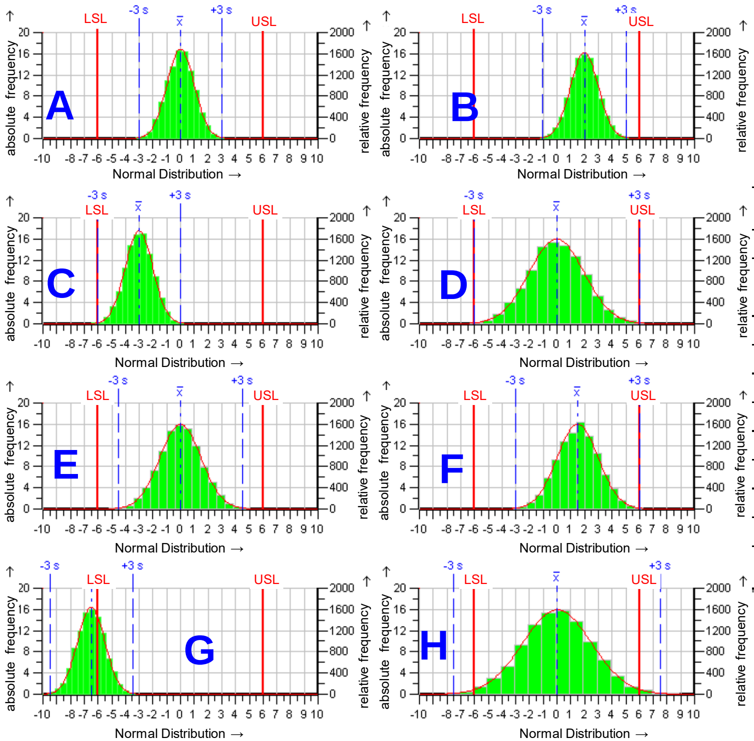
Notes:

Please Estimate Capabilities ... (Results)



Characteristics			
Char. Descr.	Index	Index	
A	2.01 (C_p)	2.01 (C_{pk})	
B	1.99 (C_p)	1.32 (C_{pk})	
C	2.00 (C_p)	0.99 (C_{pk})	
D	1.00 (C_p)	1.00 (C_{pk})	
E	1.33 (C_p)	1.33 (C_{pk})	
F	1.34 (C_p)	1.00 (C_{pk})	
G	2.00 (C_p)	-0.16 (C_{pk})	
H	0.80 (C_p)	0.80 (C_{pk})	

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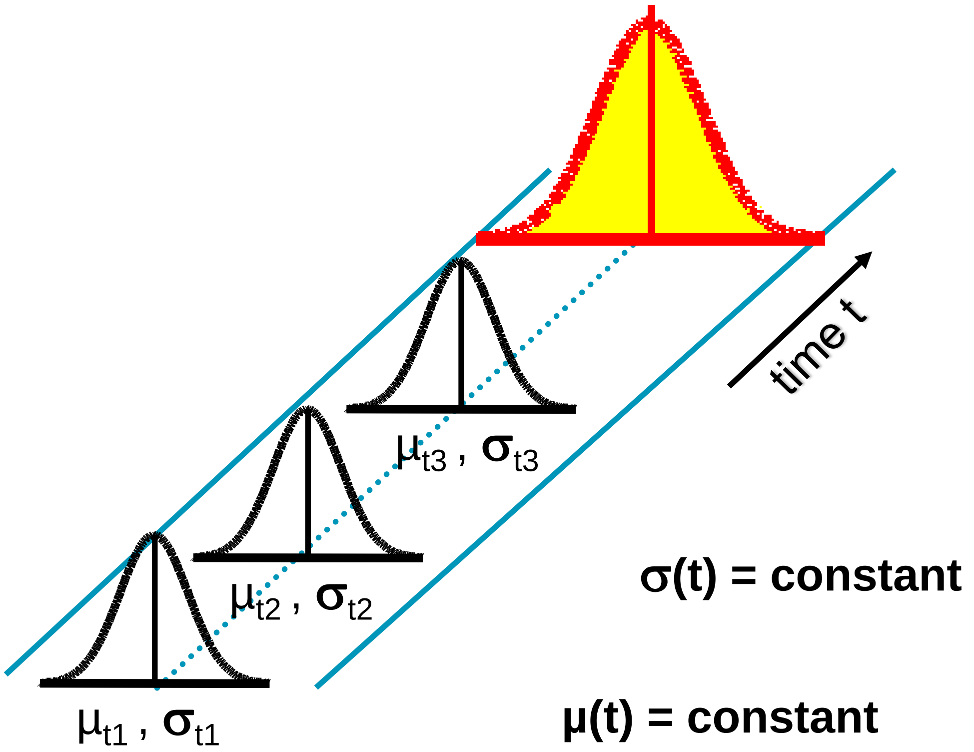
Notes:

Ideal Shewhart Process



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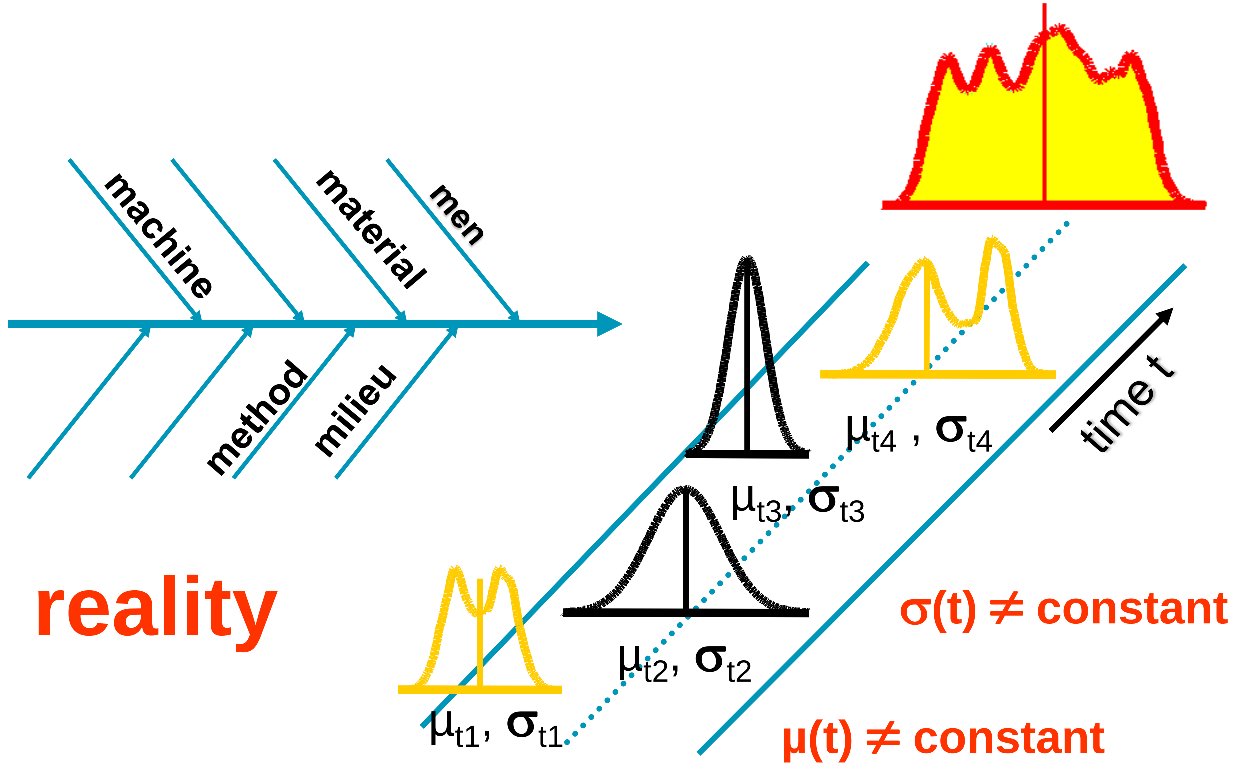
DaimlerChrysler & Ford Study 1999

only 2 % of all processes are normally distributed

Notes:

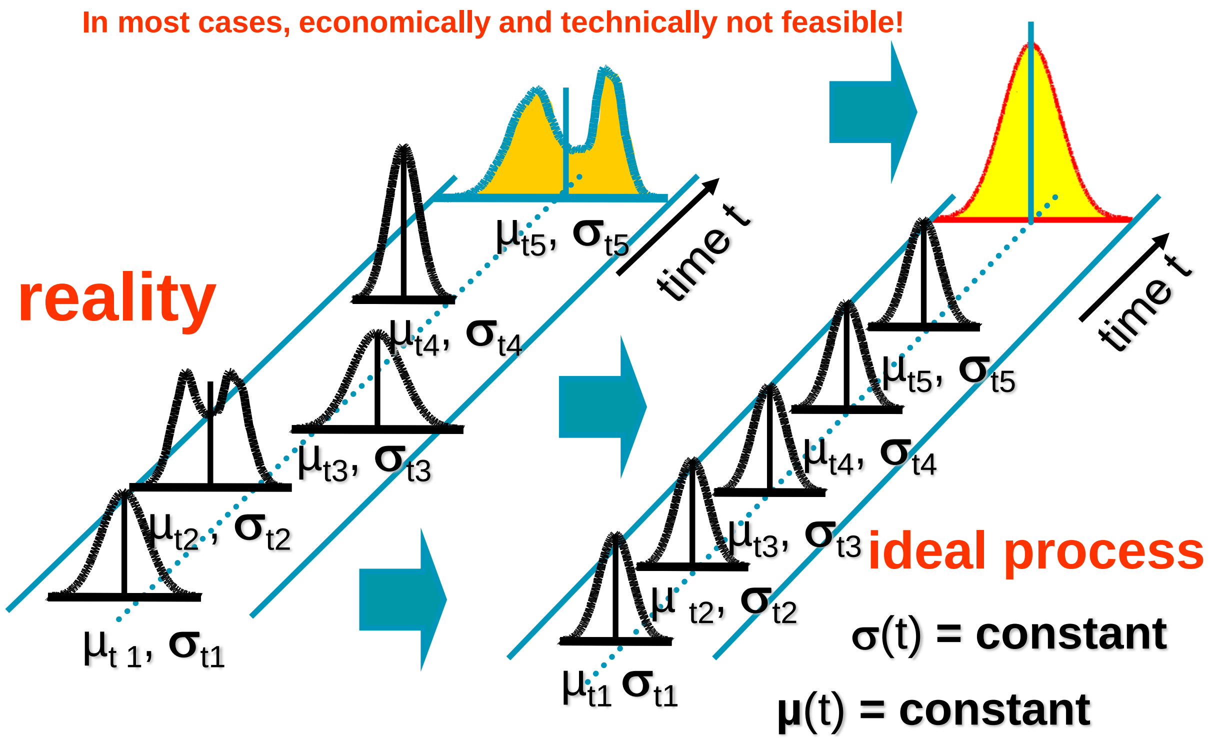
Attention: In this study, long-term processes were analysed. More normal distributions are to be expected in the case of machine acceptance.

Systematic & Random Influences



Notes:

Change of Reality



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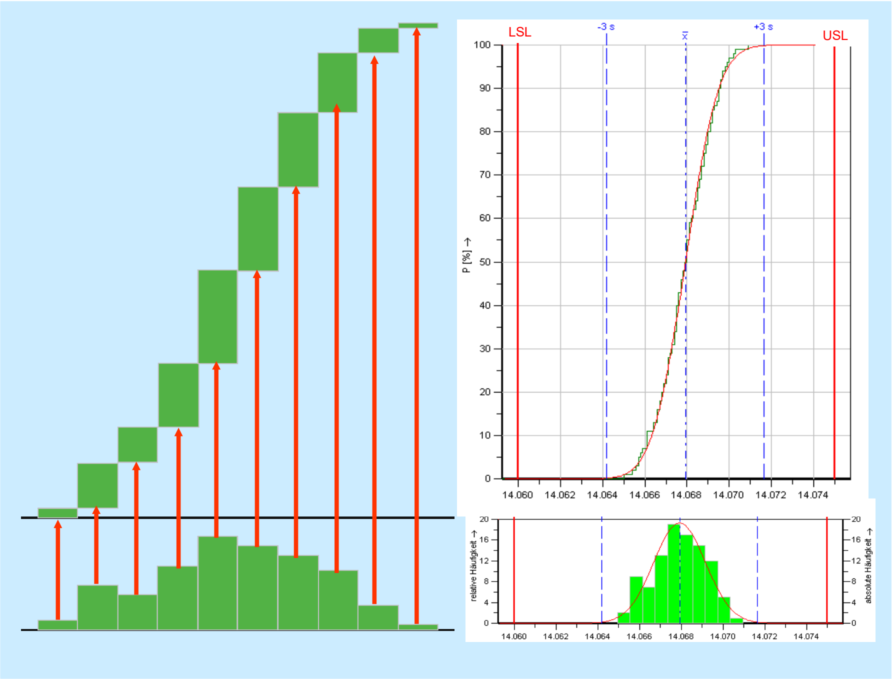
Notes:

Cumulative Line

- The histogram becomes a cumulative line.



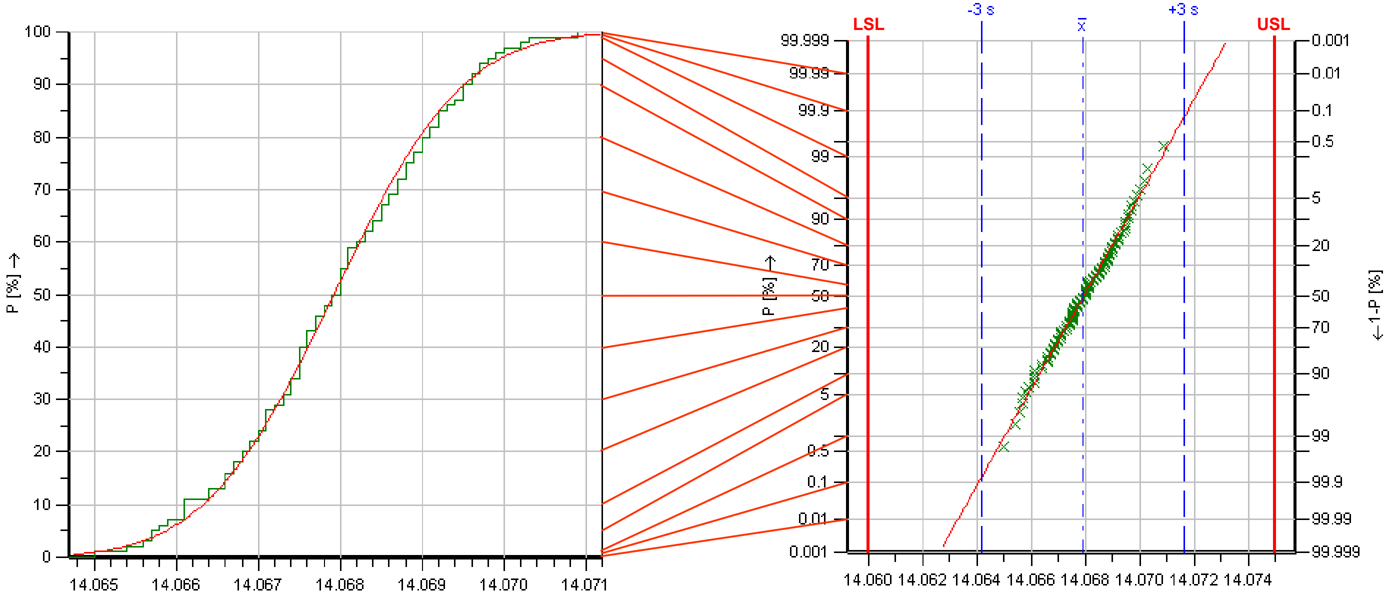
HEXAGON

Notes:

From the histogram via a cumulative representation to the cumulative line

Probability Plot

- The cumulative line becomes a probability plot.



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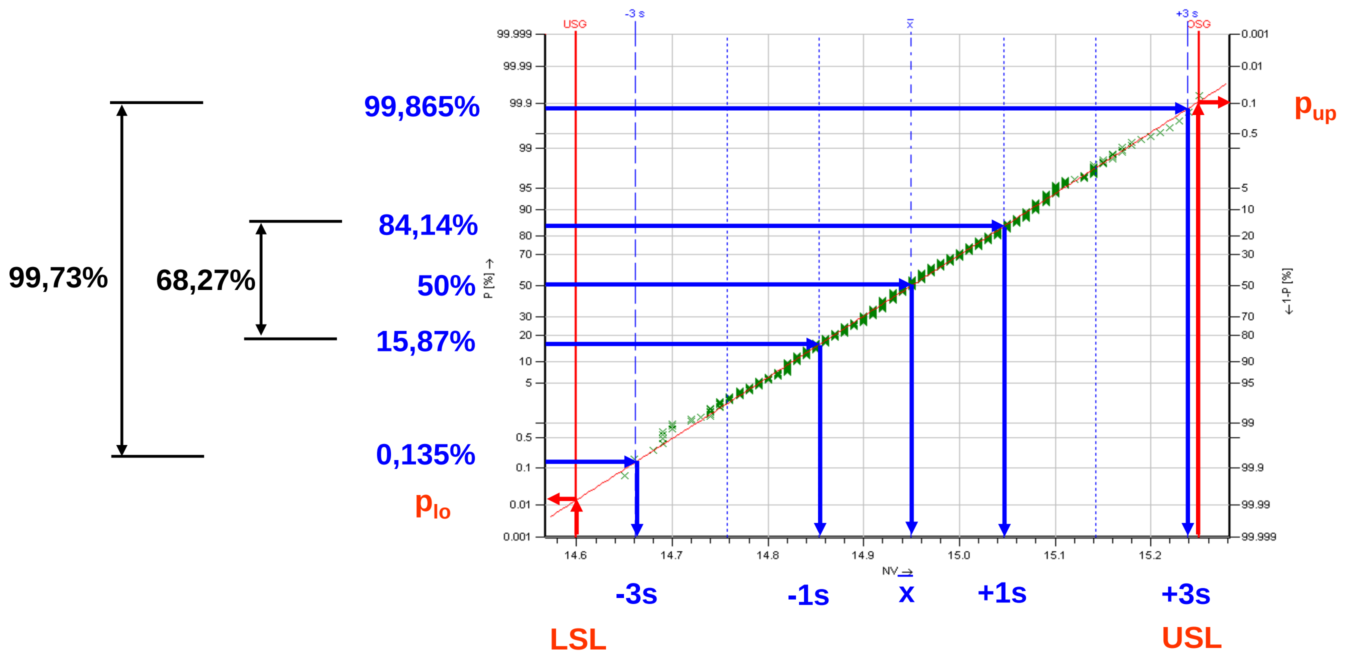
Notes:

From the cumulative line via distortion (transformation) of the axes to the probability network

Statistical Values from Probability Plot

- From the probability plot, statistical values are read



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Notes:

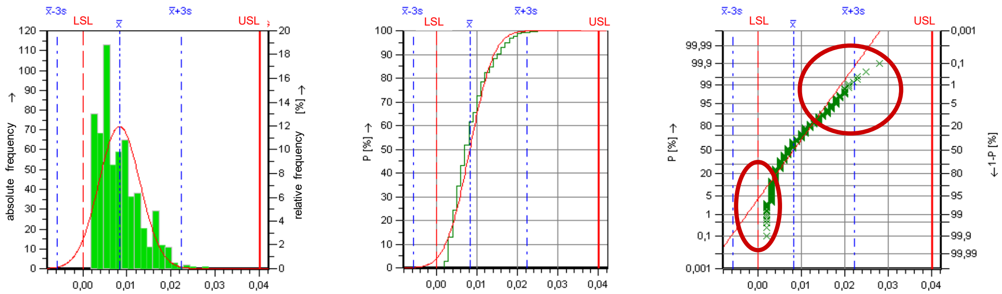
This is how characteristic values are read from the probability plot

Notes:

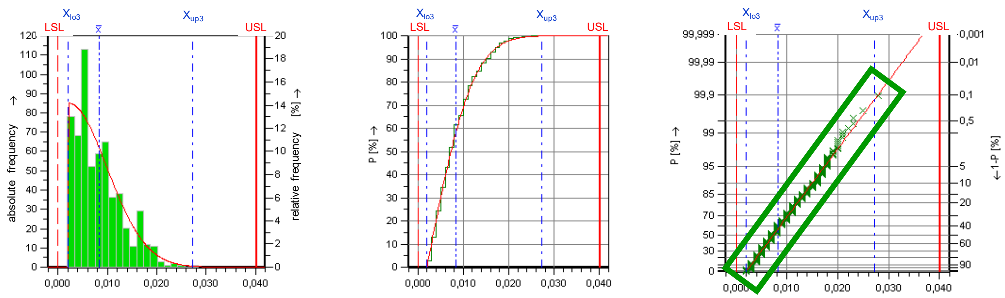
Validation of the Distribution (Probability Plot)

- Visual inspection of the distribution choice

wrong selection of distribution shape



right selection of distribution shape



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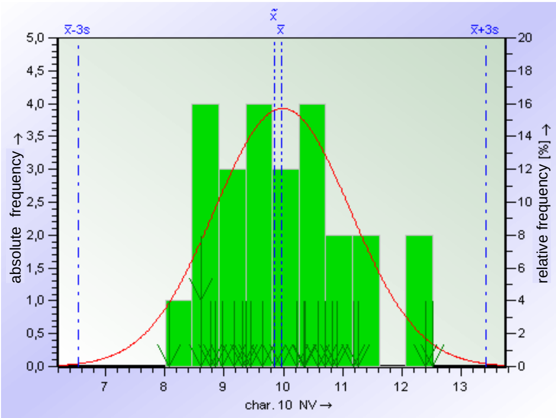
Validation of the Distribution (Probability Plot)

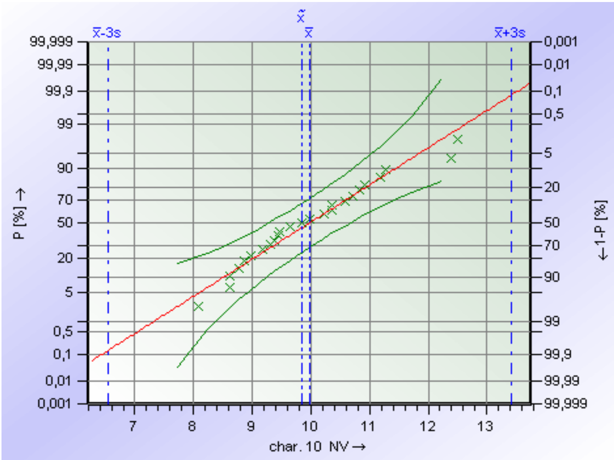
➔ Correct selection of distribution model in case of few measured values



?????? Is that right? ??????

all values within the confidence interval

no inconsistencies

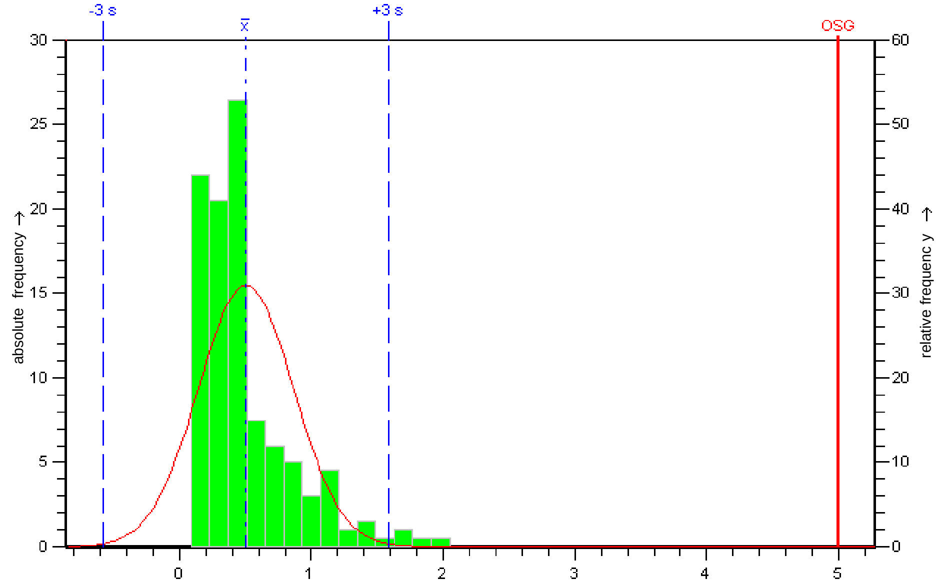


Notes:

Notes:

Standard Deviation s?

What is the standard deviation s here?



irrelevant !

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Process Variation Range in nnd Processes

- Process nnd = not normally distributed
- Standard deviation cannot be interpreted
- Standard deviation cannot be used
- But: interpretation of the standard deviation can be used
- 99.73% of the values of any distribution model can be determined
- 99.73% percentile is limited by quantiles X_{up3} und X_{lo3}
- Process variation range $= X_{up3} - X_{lo3} = X_{0,99865} - X_{0,00135}$

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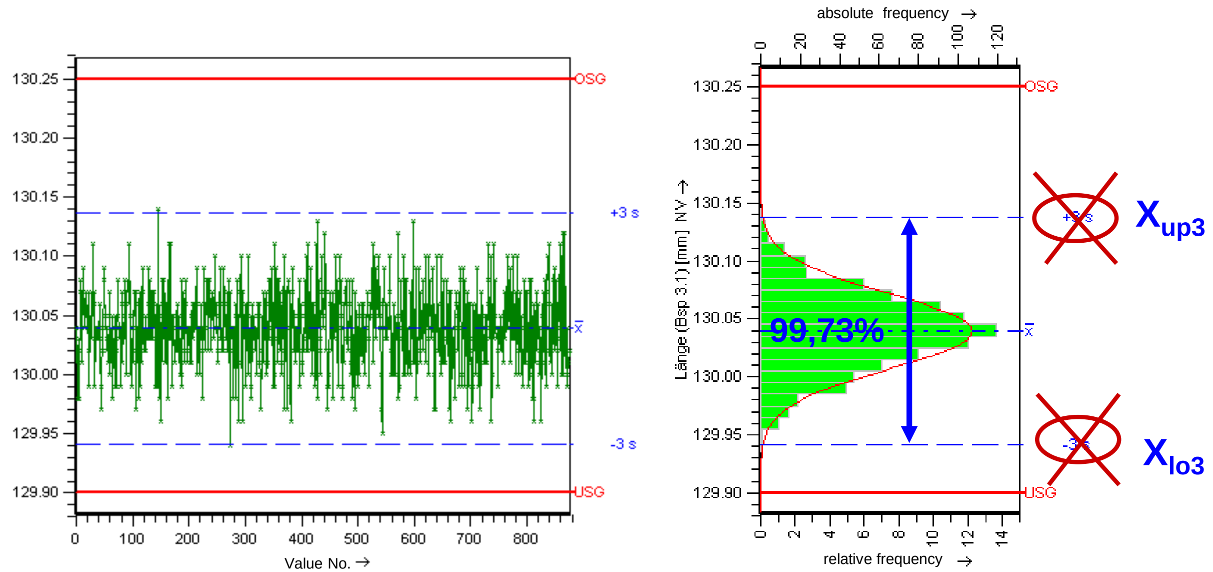
Notes:

Notes:

Process Variation Range $X_{up3} - X_{lo3}$

- Definition of the process spread via quantiles



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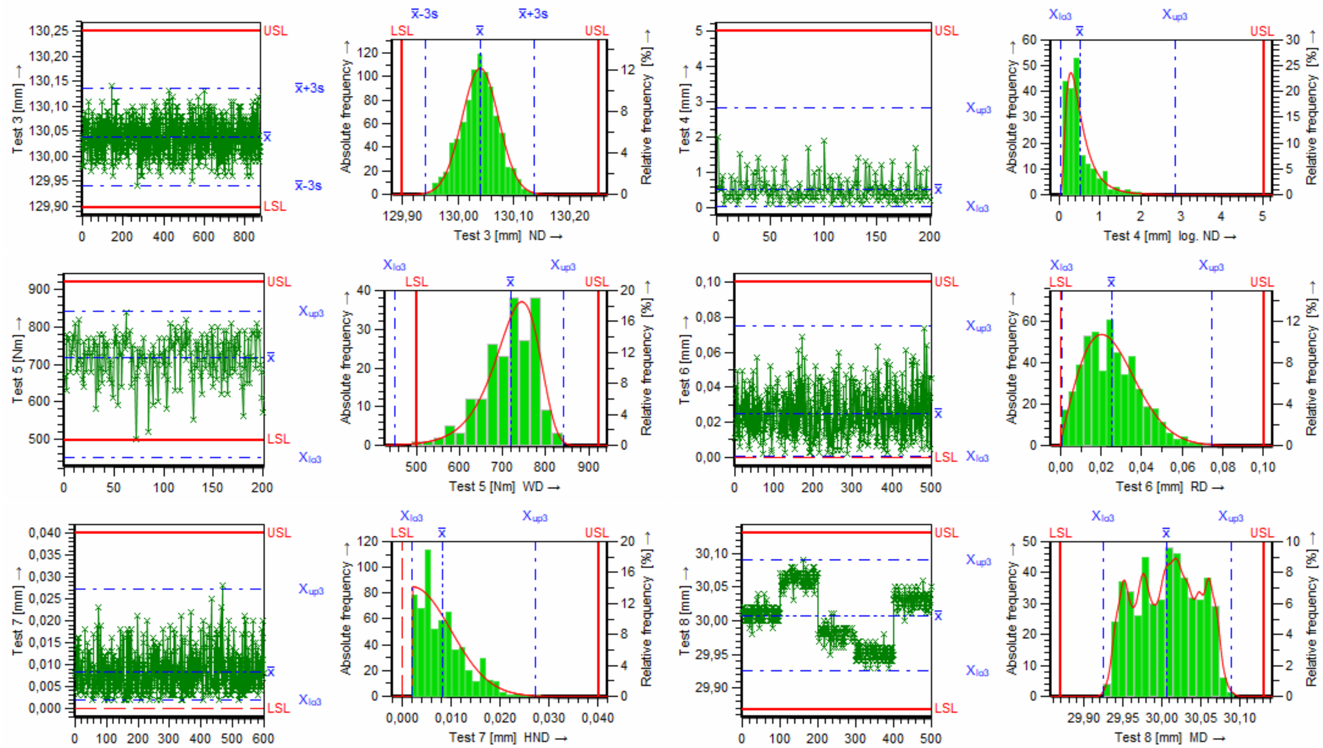
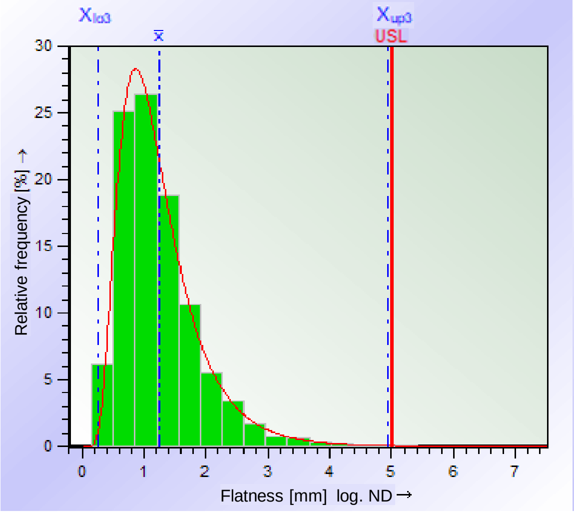
Notes:

Distribution models

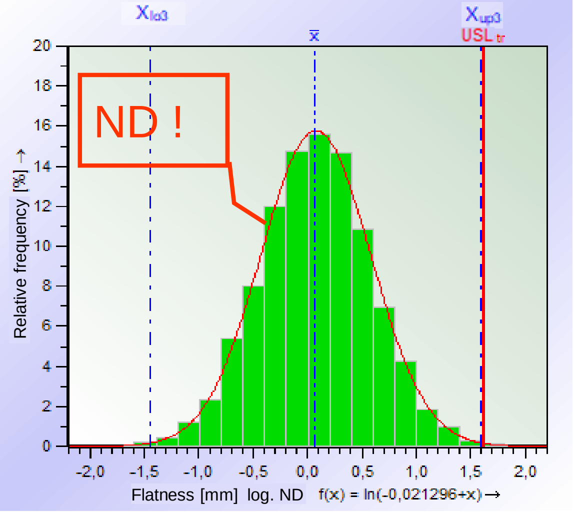


Logarithmic normal distribution

- Calculation trick, no technological justification
  - draw the logarithm from each measured value ("transform"), with offset if necessary,
  - the transformed values are to be evaluated normally distributed



real measured values



transformed measured values

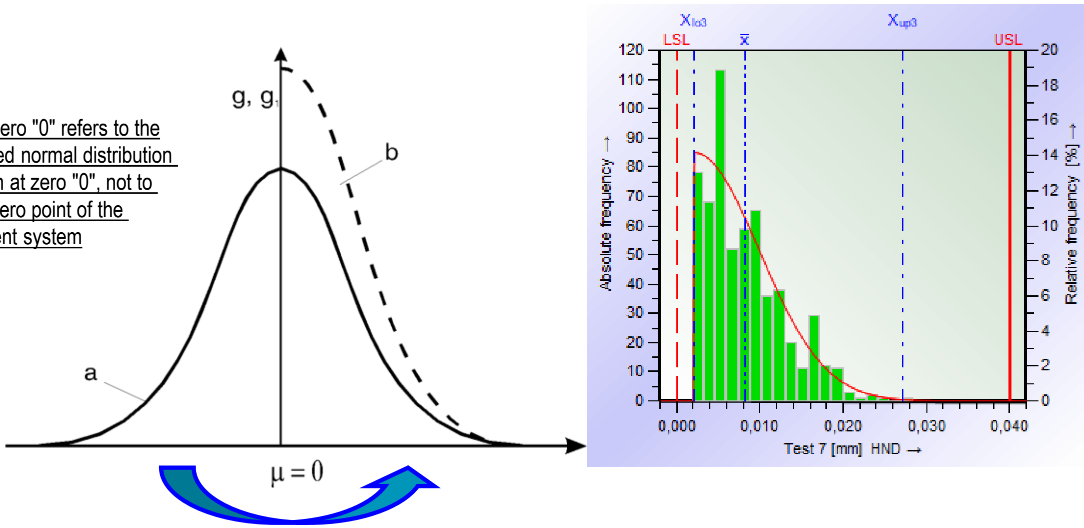
Notes:

Notes:

Half Normal / Folded Normal Distribution – HND / FND[0]

- „Half Normal Distribution HND“ or „Folded Normal Distribution FND [0]“
- „FND [0]“ means „folded at 0“, means „folded at maximum“
- One-sided naturally bounded features e.g. for univariate form and position measures
- Normally distributed characteristics evaluated by variance amount only

Note: The zero "0" refers to the standardised normal distribution with a mean at zero "0", not to the actual zero point of the measurement system



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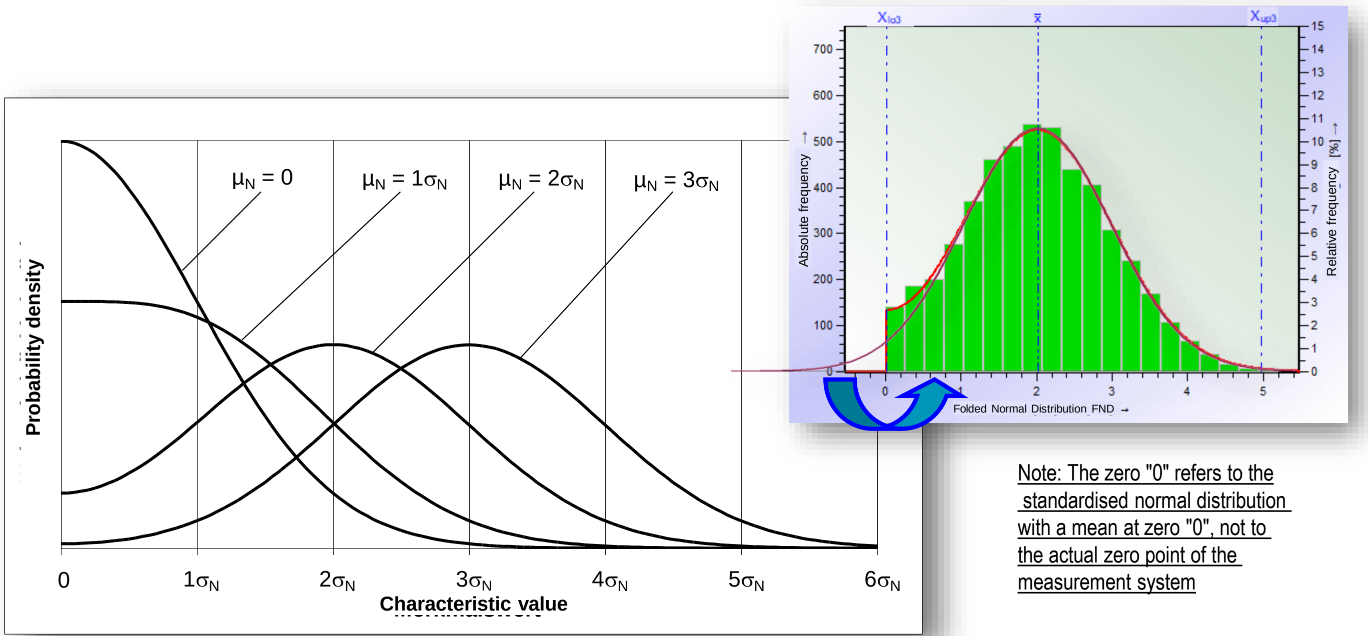
Notes:

Folded Normal Distribution – FND [<>0]

- The folding point can be at any position, it does not necessarily have to be at the maximum!
- „FND [<>0]"means "folded unequal 0"
  means "folded outside the maximum"



Note: The zero "0" refers to the standardised normal distribution with a mean at zero "0", not to the actual zero point of the measurement system

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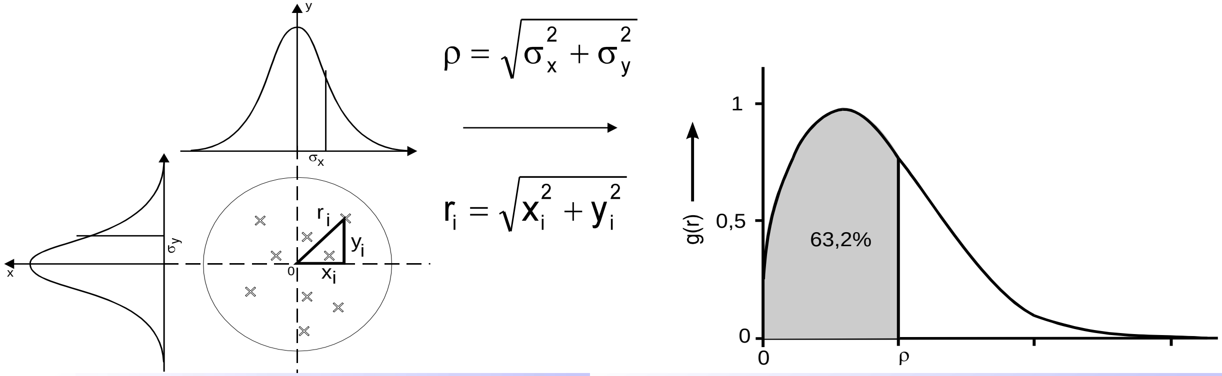
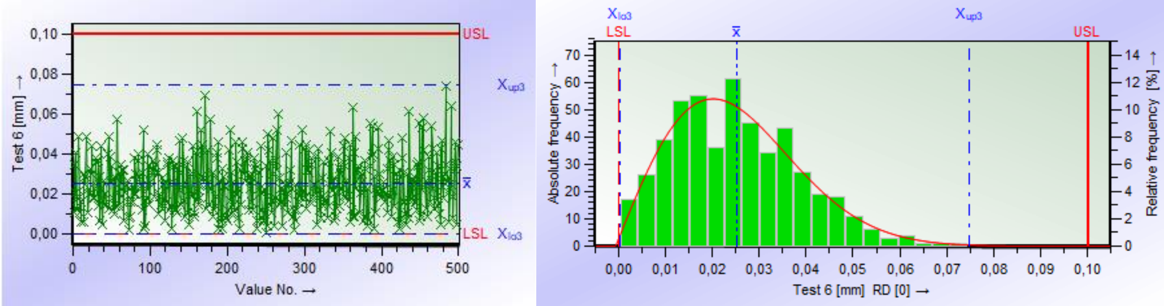
Rayleigh Distribution - RD [0]

- Two-dimensional approaches evaluated according to magnitude deviations
- Typical: position, concentricity, ...



$$\rho = \sqrt{\sigma_x^2 + \sigma_y^2}$$

$$r_i = \sqrt{x_i^2 + y_i^2}$$

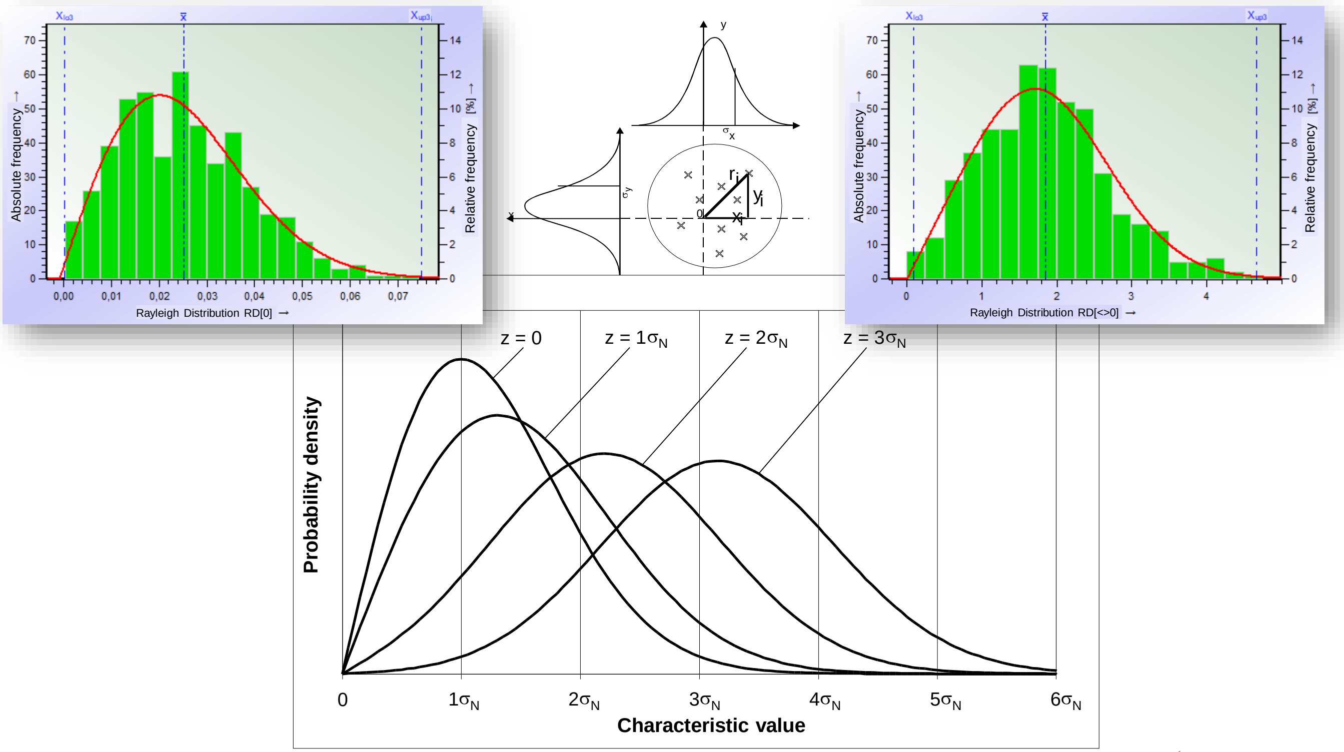


HEXAGON

Notes:

Rice Distribution / Rayleigh Distribution - RD [<>0]

- With BV2, the folding point can also lie outside the maximum



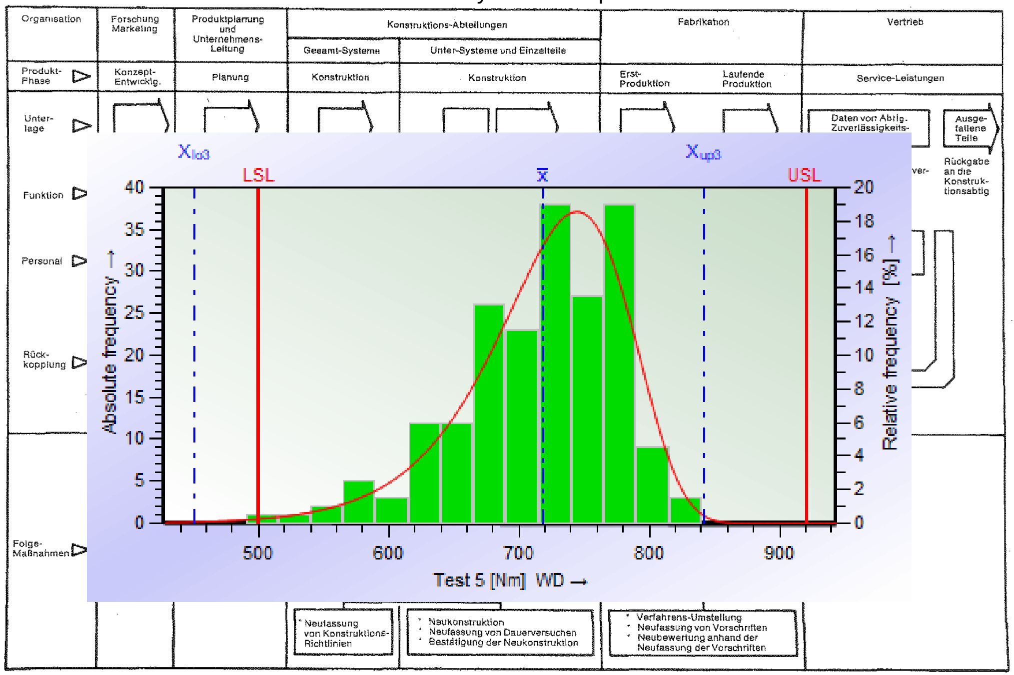
Notes:

HEXAGON

Weibull Distribution

- One-sided naturally limited at the upper side
- Highly flexible, can also approximate RD[0] and Log. NV ...

Reliability control loop



Notes:

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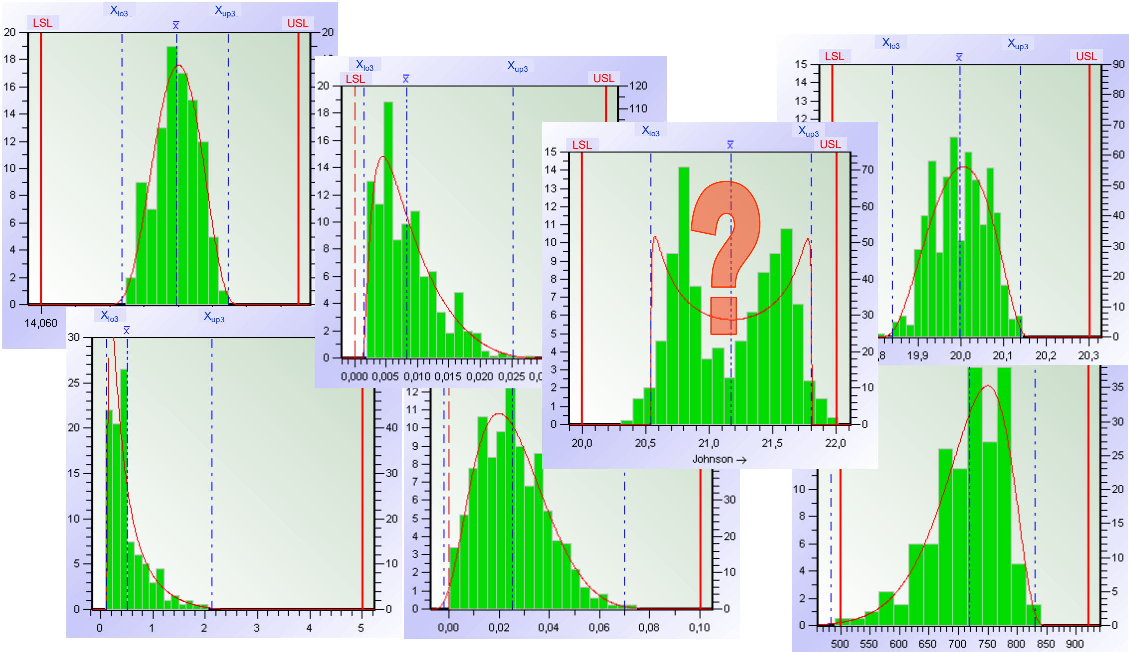
Notes:

Johnson-Transformation

- Mathematical transformation model
- Highly flexible but "formless", unimode



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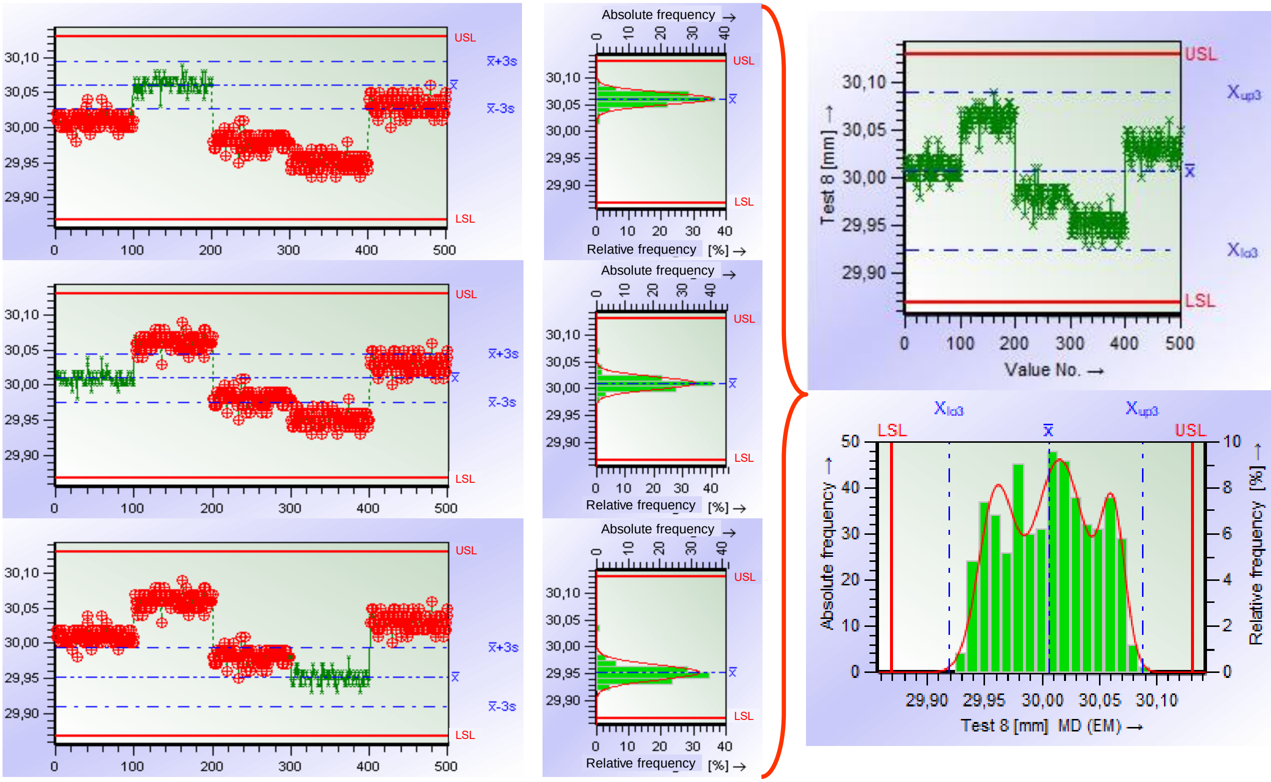
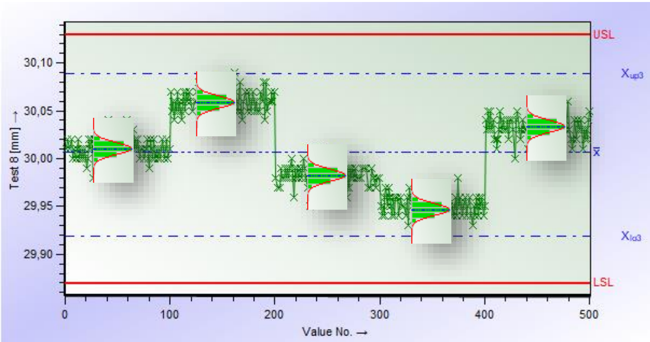
Notes:

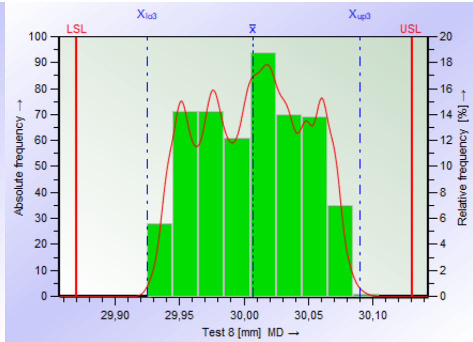
Mixed distribution (EM) with limited number of cores



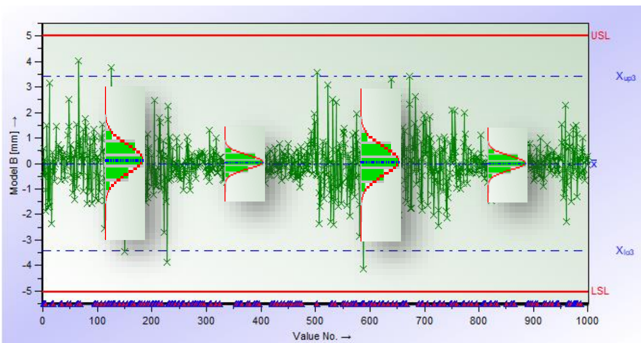
Mixed distribution does not have to be multimodal!

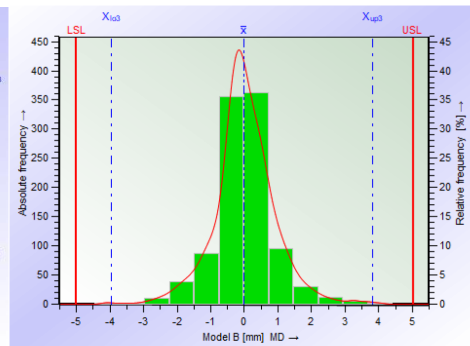
- Mixed distribution can be multimodal





- However, mixed distribution can also be unimodal





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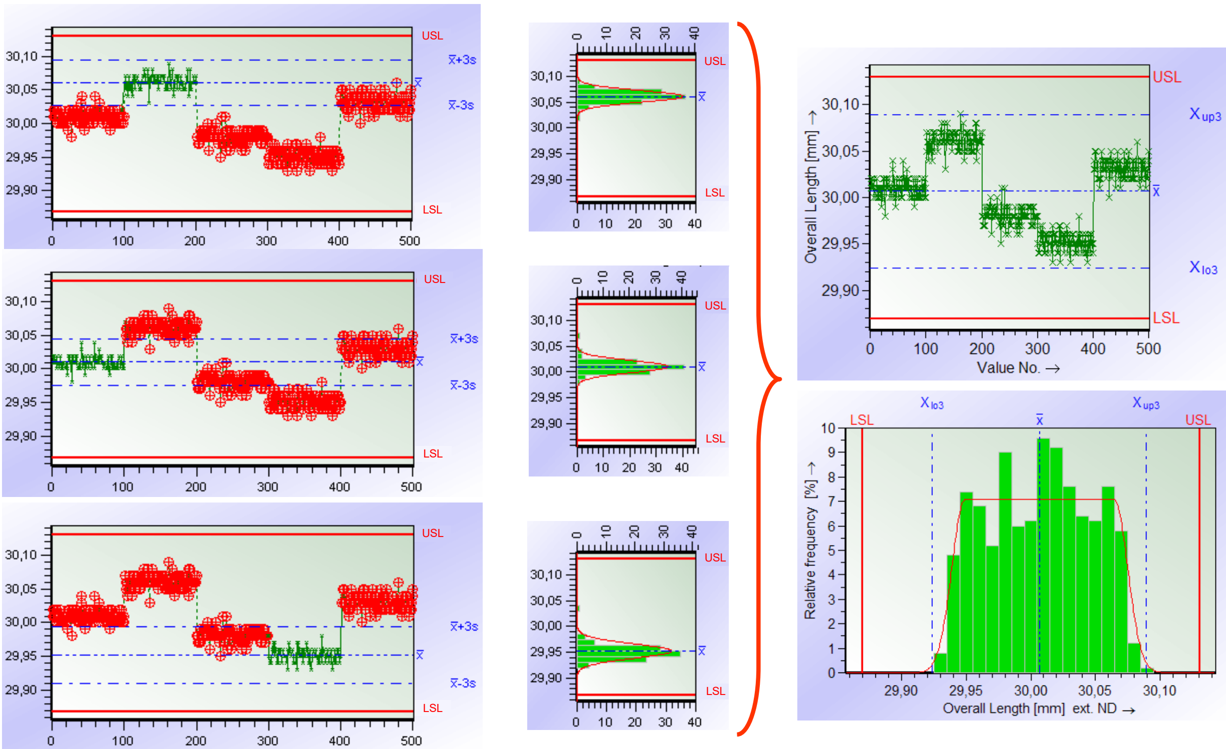
Notes:

Notes:

Extended Normal Distribution



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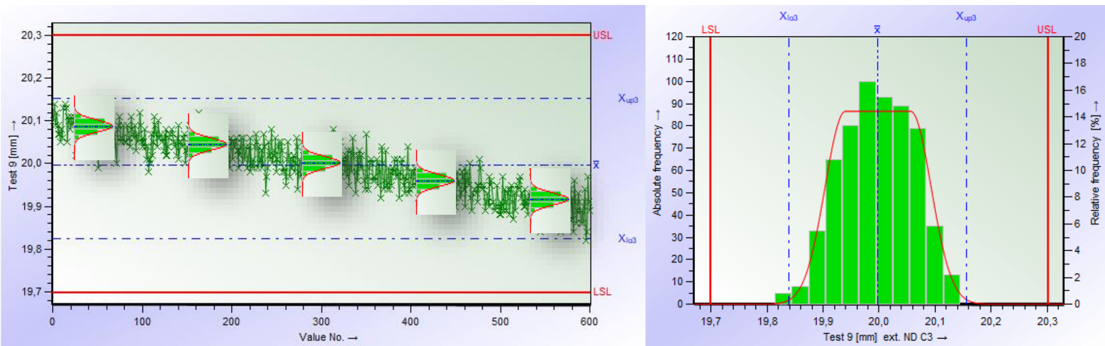
Extended normal distribution for trend processes (C3)

- Extended normal distribution for trend processes
  - Instantaneous distribution is normal distribution
  - Trend is linear and constant
  - Short-term dispersion significantly smaller than trend-related change in position



Notes:

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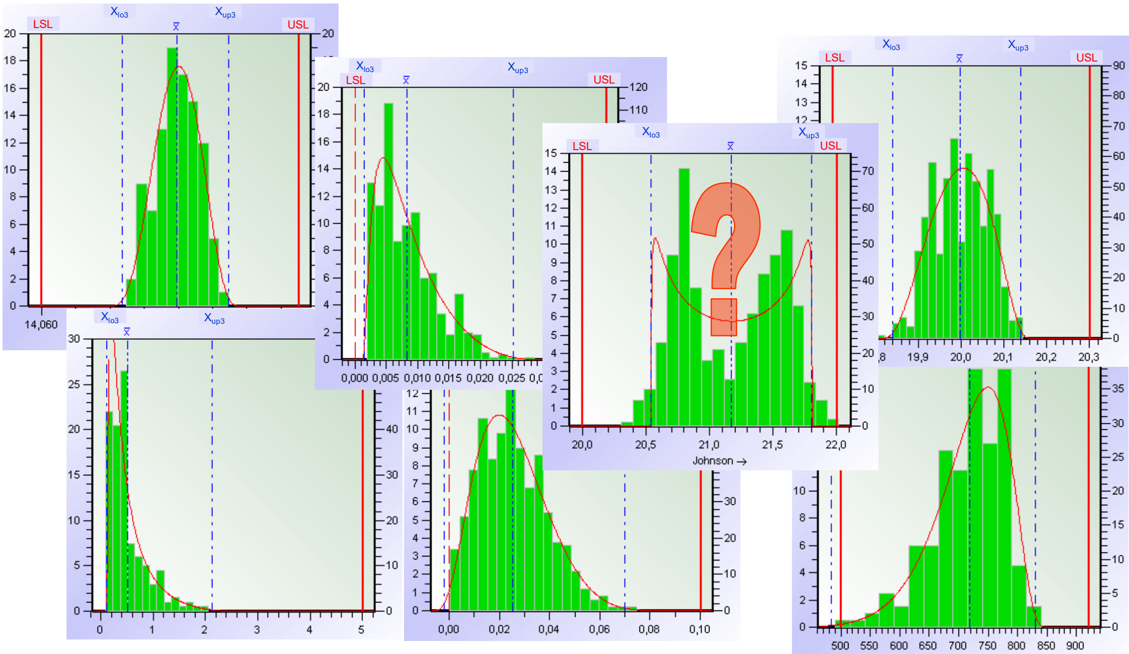
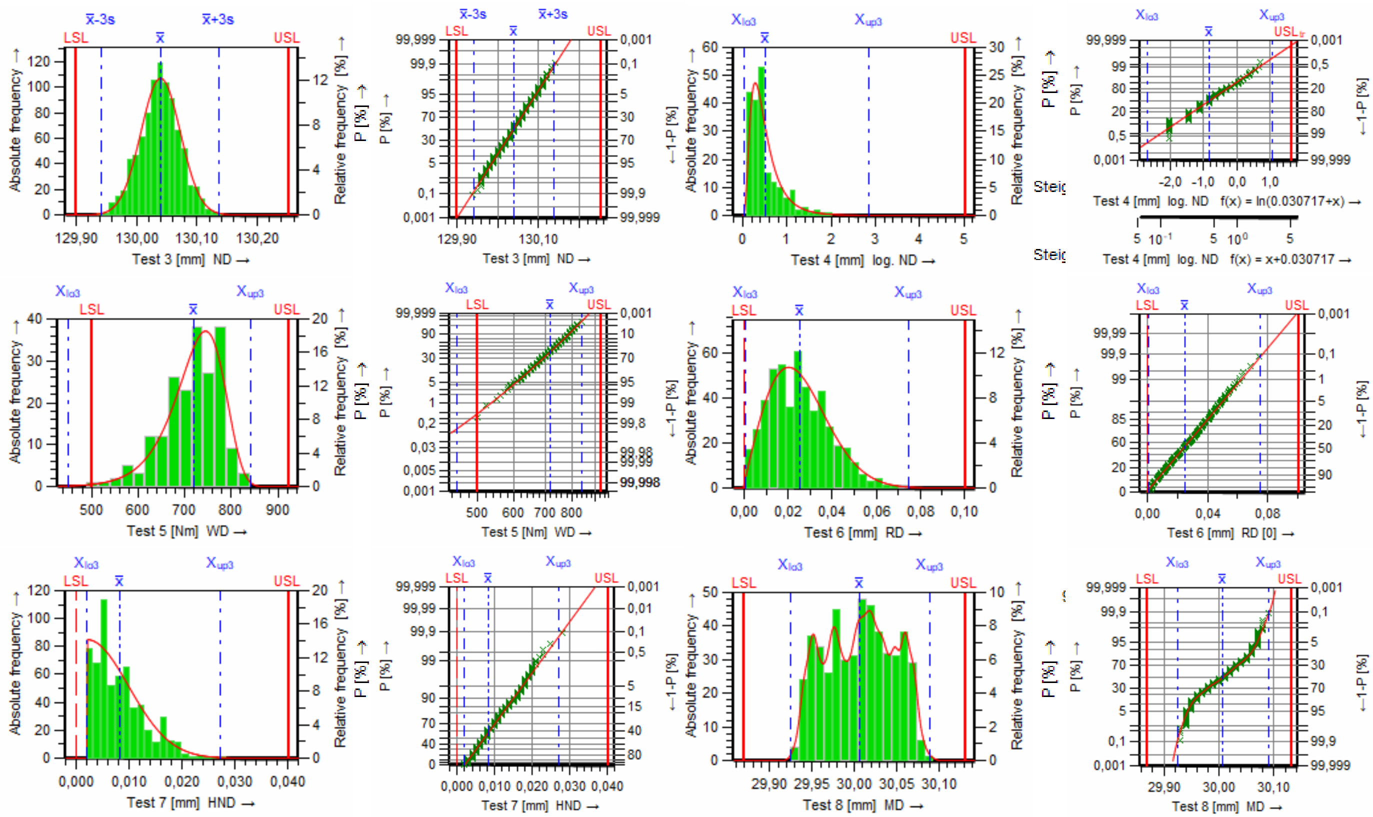
Johnson-Transformationen

- Johnson transformations were common until "Bosch 2012", have been dropped in "Bosch 2018"



Notes:

Process spread $X_{up3} - X_{lo3}$



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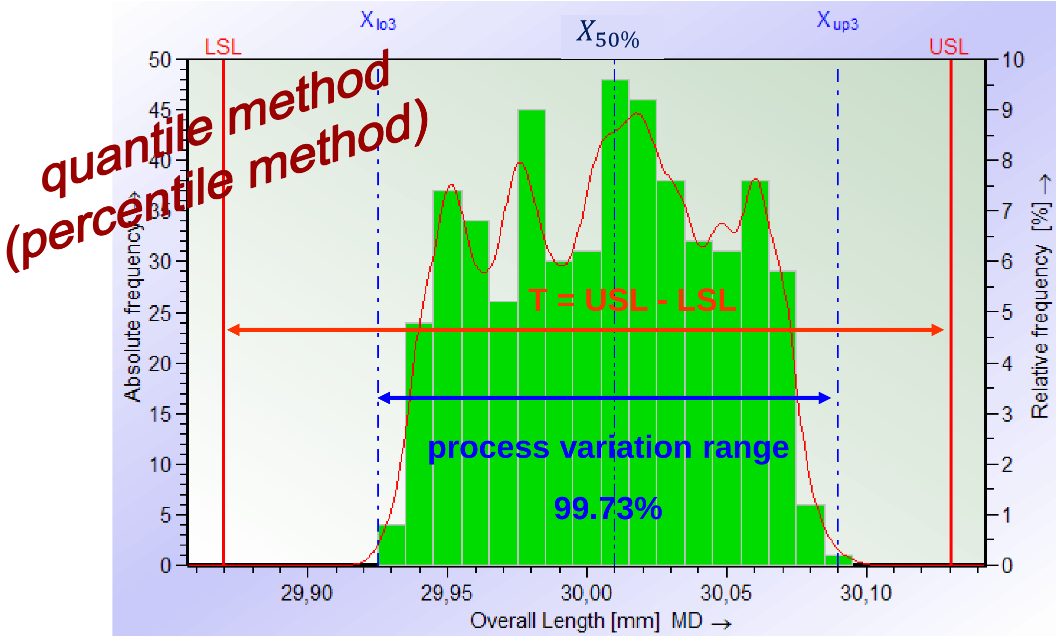
Notes:

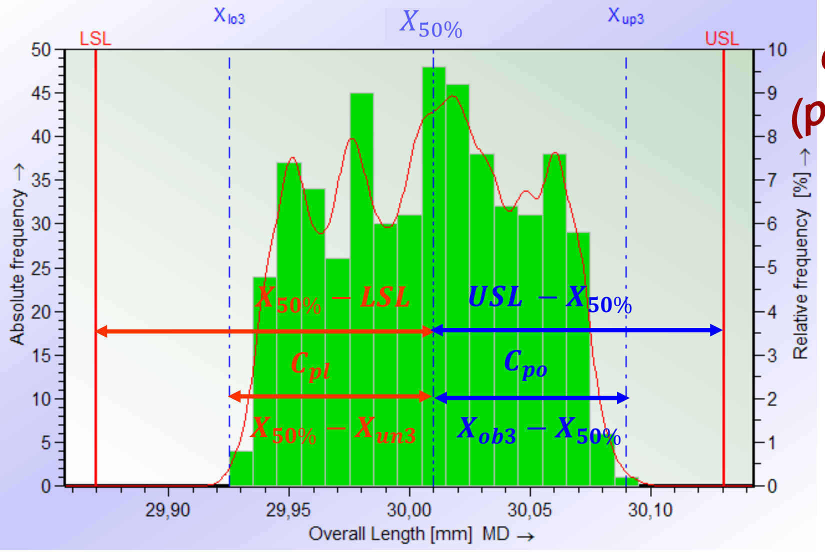
Notes:

Capability Index C_m, P_p, C_p



$$C_p = \frac{tolerance}{process\ variation\ range} = \frac{USL - LSL}{X_{up3} - X_{lo3}}$$

Capability Index C_{mk}, P_{pk}, C_{pk}



quantile method (percentile method)

Location and dispersion-based index

$$C_{pl} = \frac{X_{50\%} - LSL}{X_{50\%} - X_{un3}}$$

$$C_{pu} = \frac{USL - X_{50\%}}{X_{ob3} - X_{50\%}}$$

$$C_{pk} = min\{C_{pl}, C_{pu}\}$$

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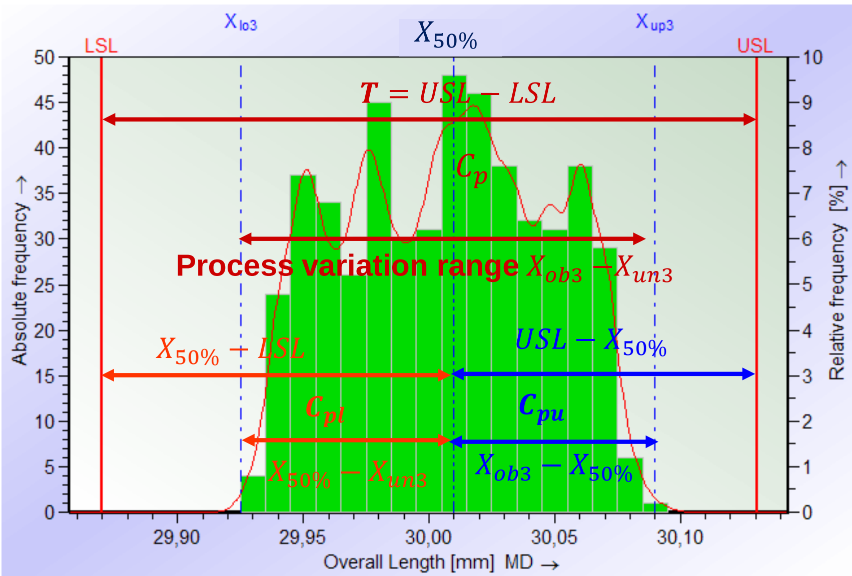
Notes:

Notes:

Capability index according to percentile/quantile method

- Quantile method (percentage method) M2.1 according to DIN ISO 22514-2



Dispersion-based index

$$C_p = \frac{USL - LSL}{X_{ob3} - X_{un3}}$$

Location and dispersion-based index

$$C_{pl} = \frac{X_{50\%} - LSL}{X_{50\%} - X_{un3}}$$

$$C_{pu} = \frac{USL - X_{50\%}}{X_{ob3} - X_{50\%}}$$

$$C_{pk} = \min\{C_{pl}, C_{pu}\}$$

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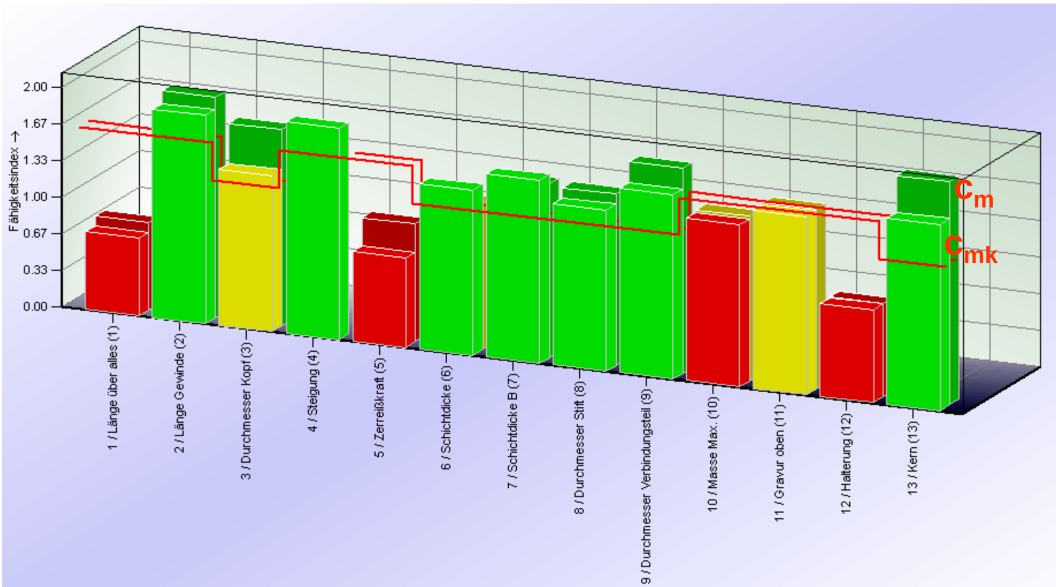
C Values Overview

One capability index pair C_m/C_{mk} per characteristic!



“capable machine“ means: all characteristics are capable

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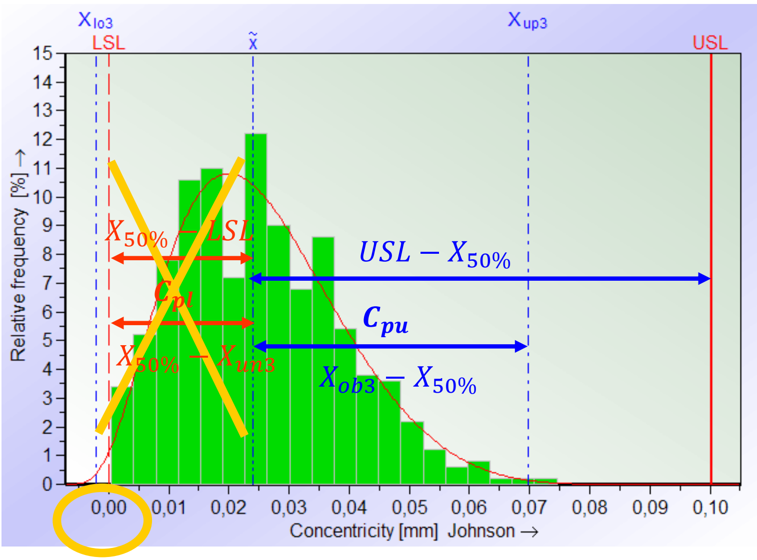
Notes:

There is no mean capability index!

Notes:

Special Case "Physically / naturally limited Characteristic"



Location and dispersion-based index

~~$C_{pl} = \frac{X_{50\%} - LSL}{X_{50\%} - X_{un3}}$~~

$$C_{pu} = \frac{USL - X_{50\%}}{X_{ob3} - X_{50\%}}$$

$$C_{pk} = C_{pu}$$

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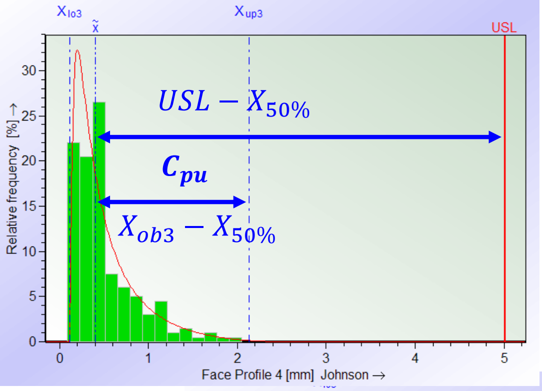
Special Case “Characteristic with One-sided Limit“

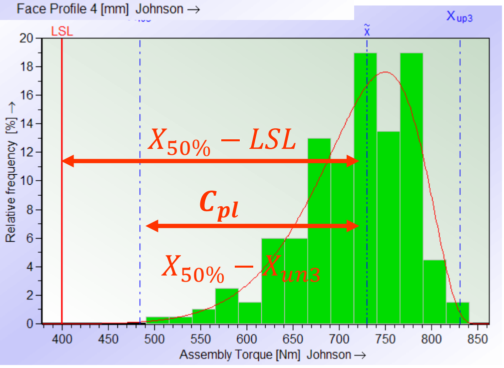


$$C_{pu} = \frac{USL - X_{50\%}}{X_{ob3} - X_{50\%}}$$

$$C_{pk} = C_{pu}$$

~~$C_p = ???$~~

C_p **cannot be calculated**



$$C_{pl} = \frac{X_{50\%} - LSL}{X_{50\%} - X_{un3}}$$

$$C_{pk} = C_{pl}$$

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Notes:

Notes:

Table of Time-dependent Distribution Models

- DIN ISO 22514-2
  Process performance and process capability parameters for continuous quality characteristics

Table 2 — Basic features of time-dependent distribution models

Characteristic	Time-dependent distribution models[a]							
	A1	A2	B	C1	C2	C3	C4	D
Location	c	c	c	r	r	s	s	s
Dispersion	c	c	s/r	c	c	c	c	s/r
Instantaneous distribution	nd	1m	nd	nd	nd	as	as	as
Resulting distribution	nd	1m	1m	nd	1m	as	as	as
Figure	1	2	3	4	5	6	7	8

Location/dispersion:
c parameter remains constant
r parameter changes randomly only
s parameter changes systematically only
Instantaneous/resulting distribution:
nd normally distributed
1m not normally distributed, one mode only
as any shape

[a] The choice of the model is a result of process analysis.

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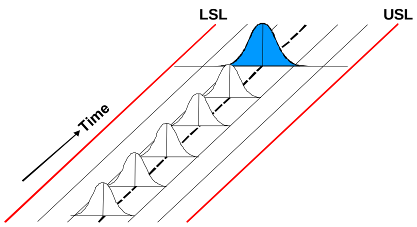
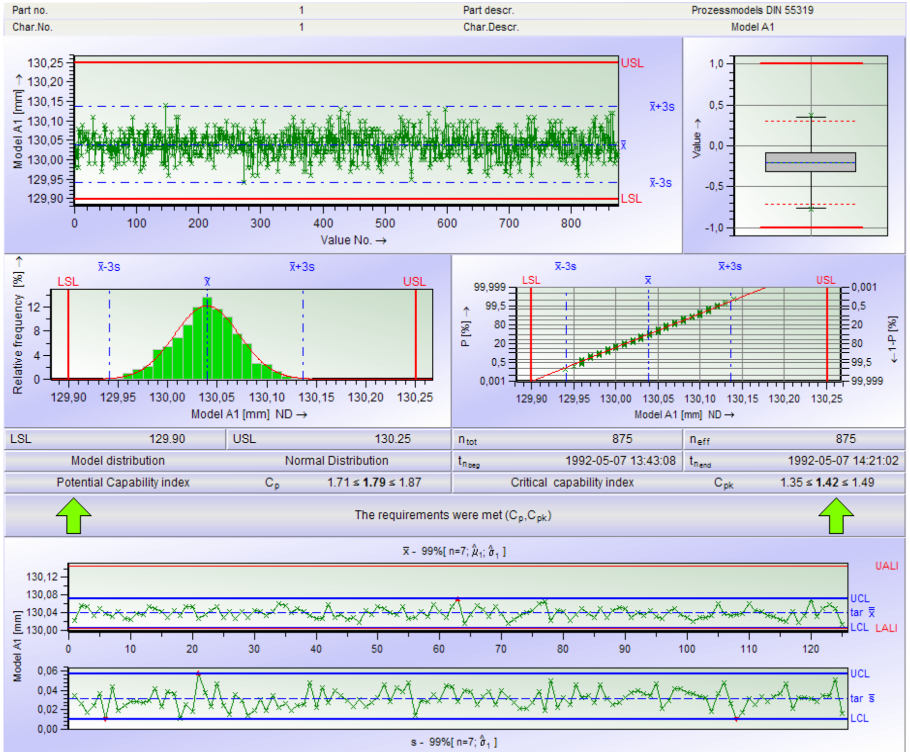
Notes:

A1 – Normally distributed stable process



- location remains constant
- variation remains constant
- skewness remains constant
- kurtosis remains constant
- current distribution
  normally distributed
- resulting distribution
  normally distributed



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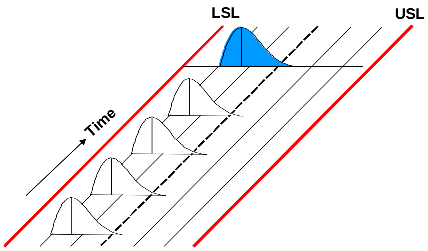
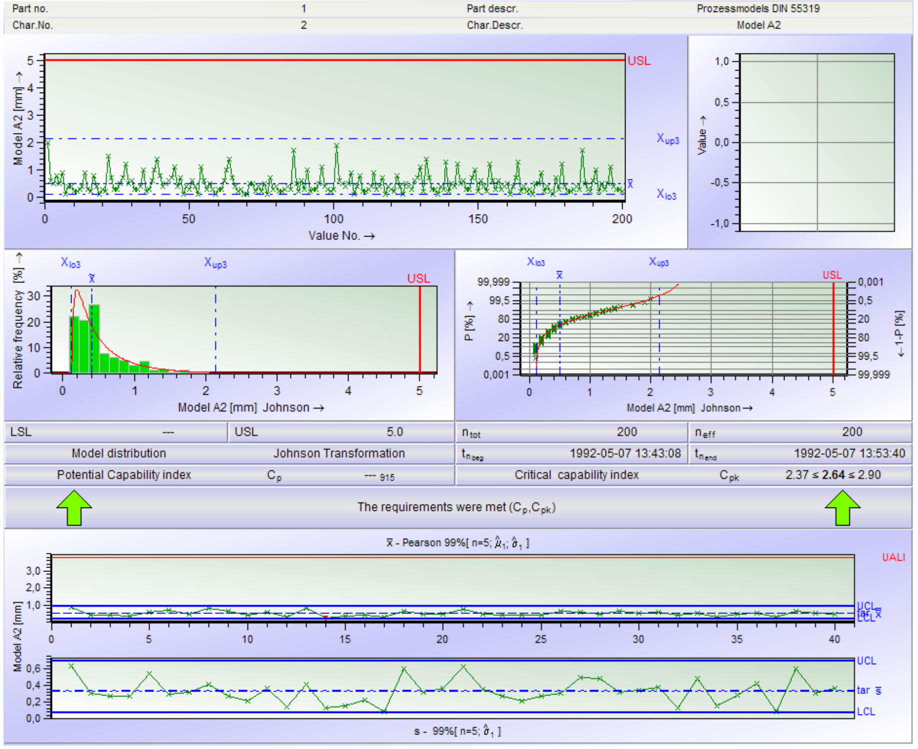
Notes:

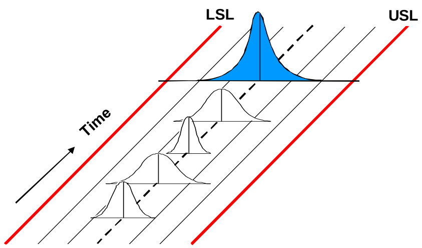
A2 – One-sided limited process



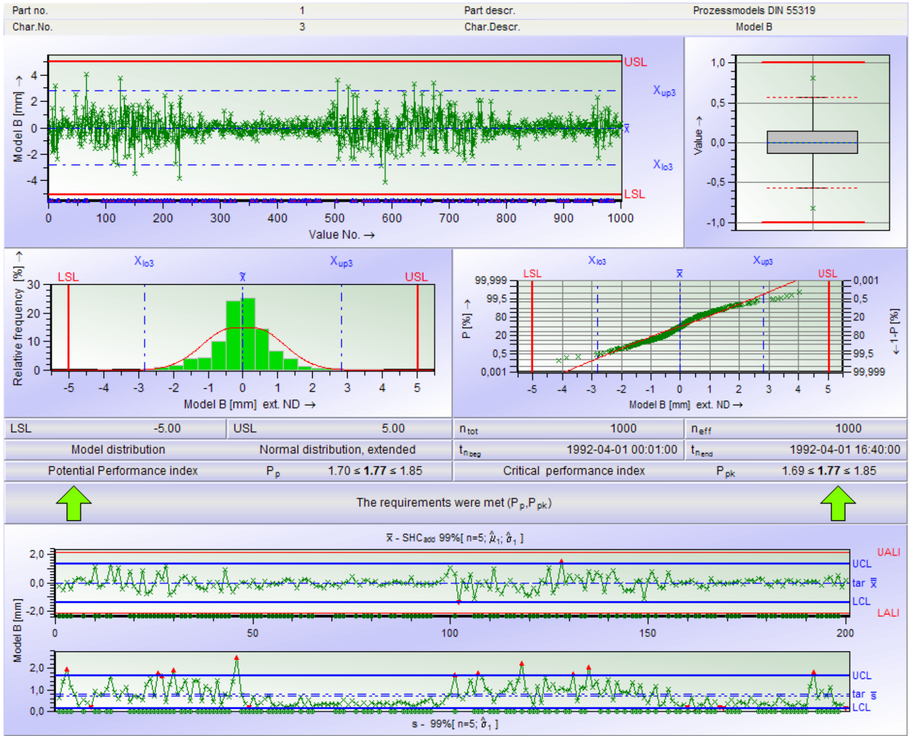


- location remains constant
- variation remains constant
- skewness remains constant
- kurtosis remains constant
- current distribution 1m
- resulting distribution 1m

B – Random variation of the dispersion



- location remains constant
- variation changes randomly
- skewness remains constant
- kurtosis remains constant
- current distribution nd
- resulting distribution 1m



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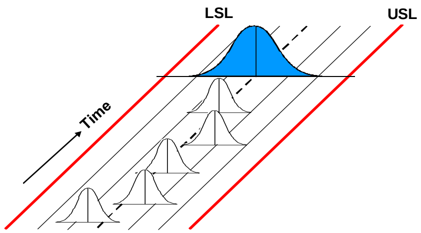
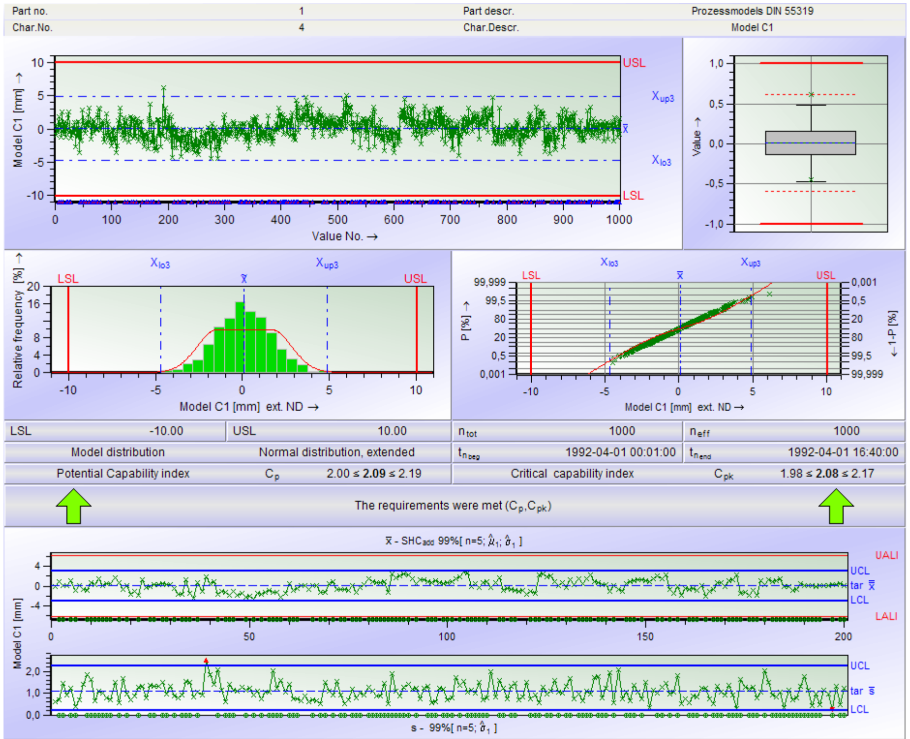
Notes:

Notes:

C1 – Random change of location (nd)





- location changes randomly (nd)
- variation remains constant
- skewness remains constant
- kurtosis remains constant
- current distribution nd
- resulting distribution nd

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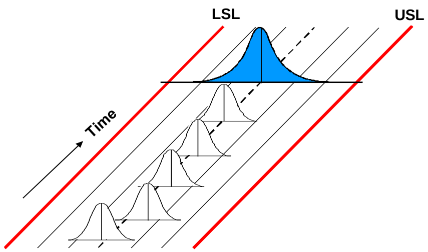
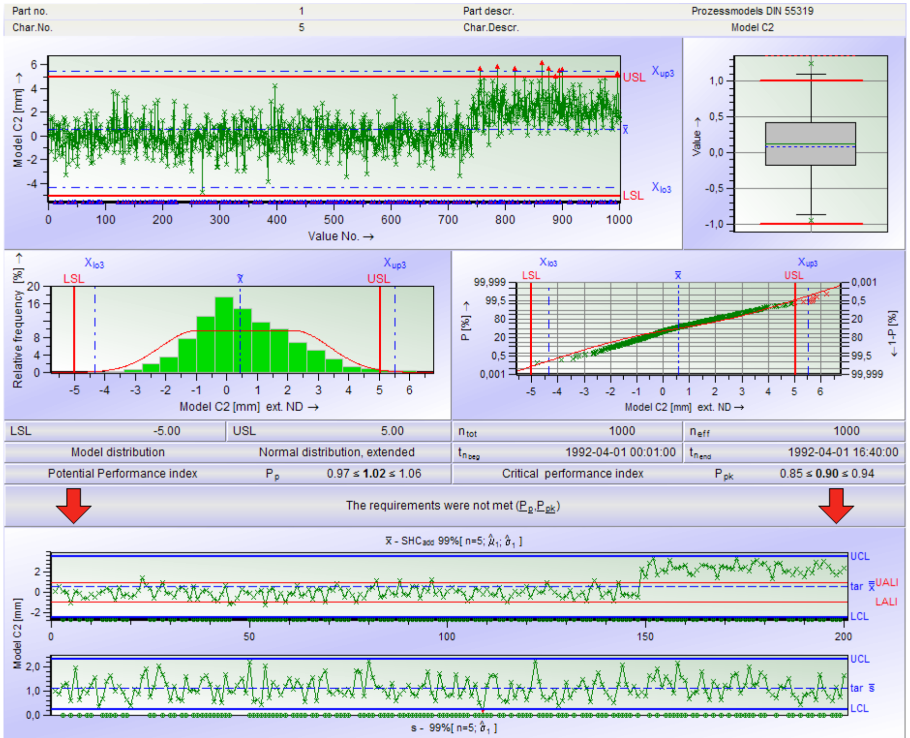
Notes:

C2 – Random change of location





- location changes randomly
- variation remains constant
- skewness remains constant
- kurtosis remains constant
- current distribution nd
- resulting distribution 1m

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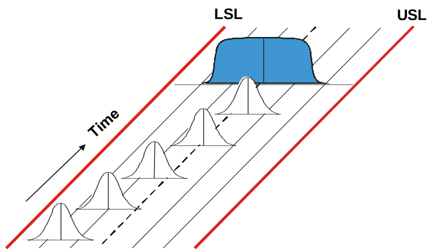
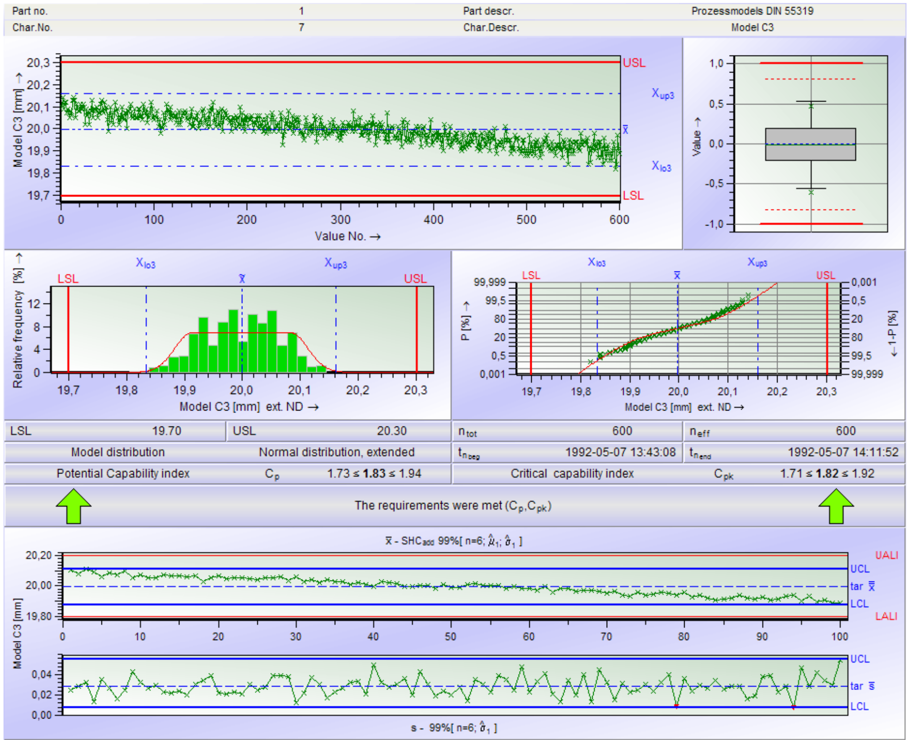
Notes:

C3 – Systematic Change of Location



- location changes systematically
- variation remains constant
- skewness remains constant
- kurtosis remains constant
- current distribution as
- resulting distribution as



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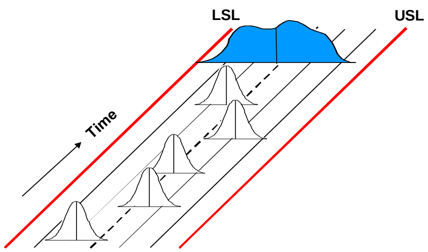
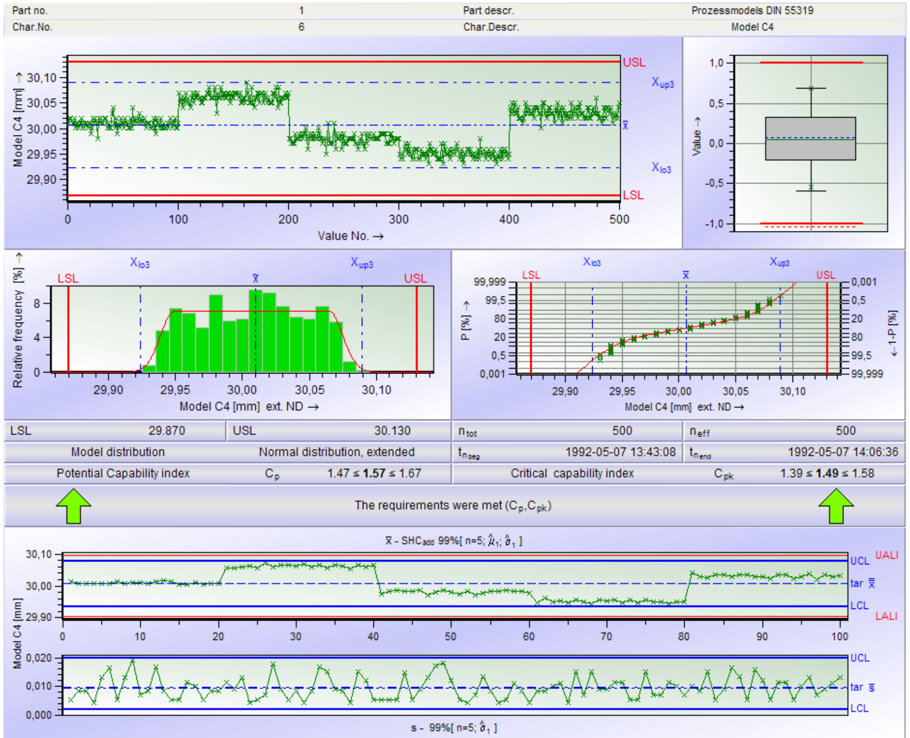
Notes:

C4 – Random and systematic changes of location





- location changes systematically and randomly
- variation remains constant
- skewness remains constant
- kurtosis remains constant
- current distribution as
- resulting distribution as

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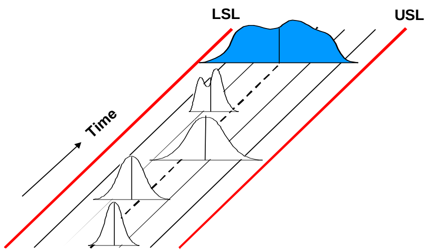
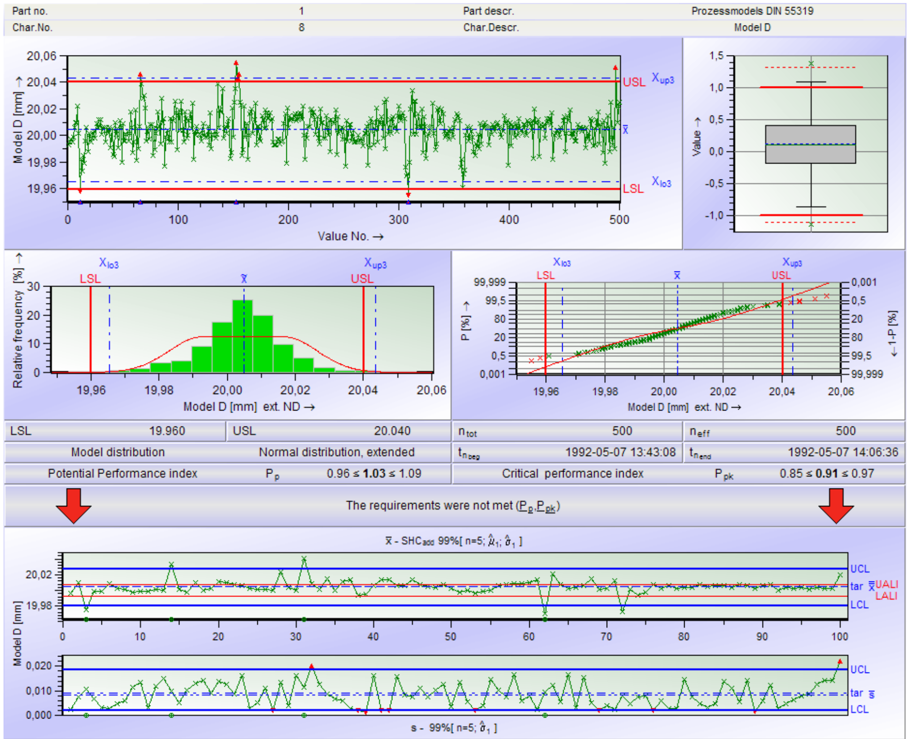
D – Arbitrary variation of location and dispersion





- location — changes systematically and randomly
- variation — ditto
- skewness — ditto
- kurtosis — ditto
- current distribution — as
- resulting distribution — as

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Notes:

Notes:

Calculation method according to DIN ISO 22514-2

- DIN ISO 22514-2 Chapter 6 Capability and performance
  - 6.1 Methods for determination of performance and capability indices — Overview

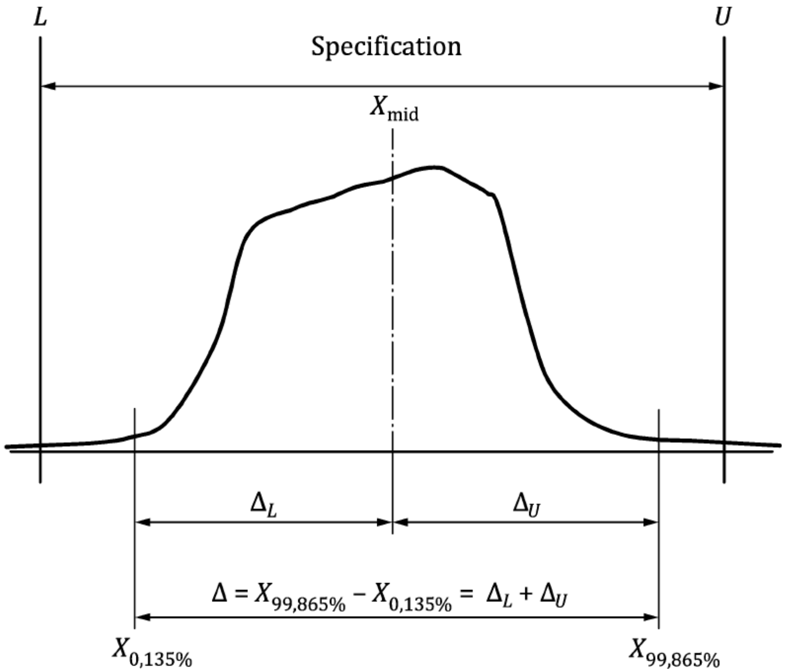

Figure 9 — Graphical representation of the general geometric method

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Calculation method according to DIN ISO 22514-2

- DIN ISO 22514-2
  Chap. 6.1.2
  Calculation of location

ATTENTION: A critical inaccuracy has crept into the standard at position $l = 2$: The median $\tilde{x}$ is usually the median of the sample, i.e. the “center" value actually measured. For small samples, this value is strongly dependent on chance. The 50%-Quantile $X_{50\%}$ is the value that separates the "upper 50%" from the "lower 50%" in the model distribution, e.g. the mean value $\bar{x}$ in the case of the normal distribution. The median of the population or the median of the model is often called $X_{50\%}$.
Bosch marks it with $l = 2^*$

Table 3 — Different methods for calculation of location

Location method label, l	Calculation method of location/Formula $M_{l,d}$	No.
1	$\hat{X}_{mid} = \bar{x} = \frac{1}{k \cdot n} \sum x_i$	(11)
2	$\hat{X}_{mid} = \tilde{x} = X_{50\%} = \left\{ \begin{array}{ll} x_{\left(\frac{n+1}{2}\right)} & ;n \text{ odd} \\ \frac{1}{2}\left[x_{\left(\frac{n}{2}\right)} + x_{\left(\frac{n}{2}+1\right)}\right] & ;n \text{ even} \end{array} \right\}$ order statistic x_i	(12)
3	$\hat{X}_{mid} = \bar{\bar{x}} = \frac{1}{k} \sum \bar{x}_i$	(13)
4	$\hat{X}_{mid} = \bar{\tilde{x}} = \frac{1}{k} \sum \tilde{x}_i$	(14)

x_i individual values
n number of values
$\bar{x}_i$ average of the ith subgroup
k number of subgroups of size n
$\tilde{x}_i$ median of the ith subgroup

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Notes:

Calculation method according to DIN ISO 22514-2

- DIN ISO 22514-2
  Chap. 6.1.3
  Calculation of dispersion

Table 4 — Different methods for calculation of dispersion

Dispersion method label, d	Calculation method of dispersion/Formula $M_{l,d}$	No.
1	$\hat{\Delta} = X_{99,865\%} - X_{0,135\%}$; $\hat{\Delta}_U = X_{99,865\%} - X_{\text{mid}}$; $\hat{\Delta}_L = X_{\text{mid}} - X_{0,135\%}$	(15)
2	$\hat{\Delta} = 6\hat{\sigma}$; $\hat{\Delta}_U = 3\hat{\sigma}$; $\hat{\Delta}_L = 3\hat{\sigma}$ where $\hat{\sigma} = \sqrt{\frac{\sum s_i^2}{k}}$	(16)
3	$\hat{\Delta} = 6\hat{\sigma}$; $\hat{\Delta}_U = 3\hat{\sigma}$; $\hat{\Delta}_L = 3\hat{\sigma}$ where $\hat{\sigma} = \frac{\sum s_i}{k \cdot c_4}$	(17)
4	$\hat{\Delta} = 6\hat{\sigma}$; $\hat{\Delta}_U = 3\hat{\sigma}$; $\hat{\Delta}_L = 3\hat{\sigma}$ where $\hat{\sigma} = \frac{\sum R_i}{k \cdot d_2}$	(18)
5	$\hat{\Delta} = 6\hat{\sigma}$; $\hat{\Delta}_U = 3\hat{\sigma}$; $\hat{\Delta}_L = 3\hat{\sigma}$ where $\hat{\sigma} = s_t = \sqrt{\frac{1}{n-1}\sum (x_i - \bar{x})^2}$	(19)

s_i^2 variance of the ith subgroup
s_i standard deviation of the ith subgroup
k number of subgroups of size n
R_i range of the ith subgroup
s_t standard deviation of the whole data set

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Notes:

Calculation method according to DIN ISO 22514-2

- DIN ISO 22514-2 Chap. 6. 3
  Use of different calculation methods

Table 5 — Process capability indices

	Time model	A1	A2	B	C1	C2	C3	C4	D
Location calculation	1	a		a					
	2	a	a	a	a	a	a	a	a
	3	a							
	4	a	a	a					
Dispersion calculation	1	a	a	a	a	a	a	a	a
	2	a							
	3	a							
	4	a							
	5	a	a	a	a				a

[a] Indicates those methods which could be used for the calculation of indices.

Bosch:

Location estimator $l = 2^*$
with 50%-Quantile $X_{50\%}$
$\hat{X}_{mid} = X_{50\%}$

Dispersion estimator $d = 1$
$\hat{\Delta} = X_{99,865\%} - X_{0,135\%}$

$$C_p = \frac{U - L}{X_{99,865\,\%} - X_{0,135\,\%}}$$

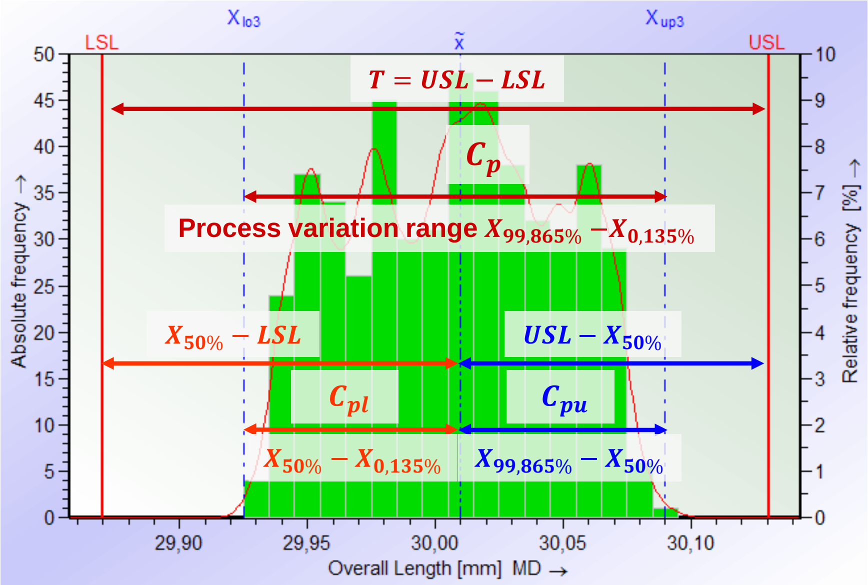
$$C_{pkL} = \frac{X_{50\,\%} - L}{X_{50\,\%} - X_{0,135\,\%}} \qquad C_{pkU} = \frac{U - X_{50\,\%}}{X_{99,865\,\%} - X_{50\,\%}}$$

$$C_{pk} = \min\{C_{pkL}, C_{pkU}\}$$

Notes:

Capability index according to percentile/quantile method M2.1

- Percentile / quantile method (general geometric method) according to DIN ISO 22514-2



Dispersion-based index

$$C_p = \frac{USL - LSL}{X_{ob3} - X_{un3}}$$

Location and dispersion-based index

$$C_{pl} = \frac{X_{50\%} - LSL}{X_{50\%} - X_{un3}}$$

$$C_{pu} = \frac{USL - X_{50\%}}{X_{ob3} - X_{50\%}}$$

$$C_{pk} = \min\{C_{pl}, C_{pu}\}$$

- With location parameter quantile $X_{50\%}$ (preferred) or sample median $\tilde{x}$ (if meaningful)

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Notes:

Notes:

Reporting of the key figures

- Example of reporting in DIN ISO 22514-2

Table 6 — Example of report of calculated process capability indices

Process performance/capability index	$C_p = 1{,}68$
Minimum process performance/capability index	$C_{pk} = 1{,}47$
Calculation method	$M_{1,1}$
Number of values used for the calculation	2 000
Measurement uncertainty	0,002 mm
Time distribution model	A1
Calculation method $M_{1,1}$ means that the capability calculation is done using the average and the reference interval as estimators for location and dispersion.	

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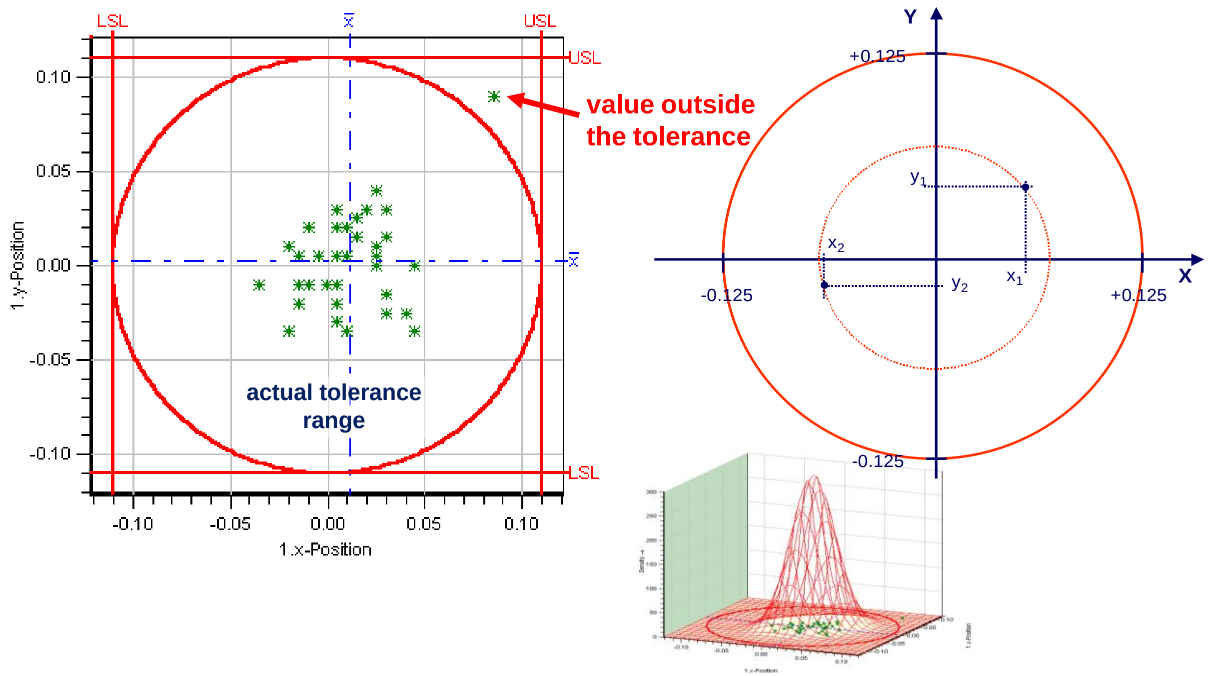
Positional Tolerances - Basics



Notes:

Tolerance of the axes and radial view leads to elliptical tolerance range.

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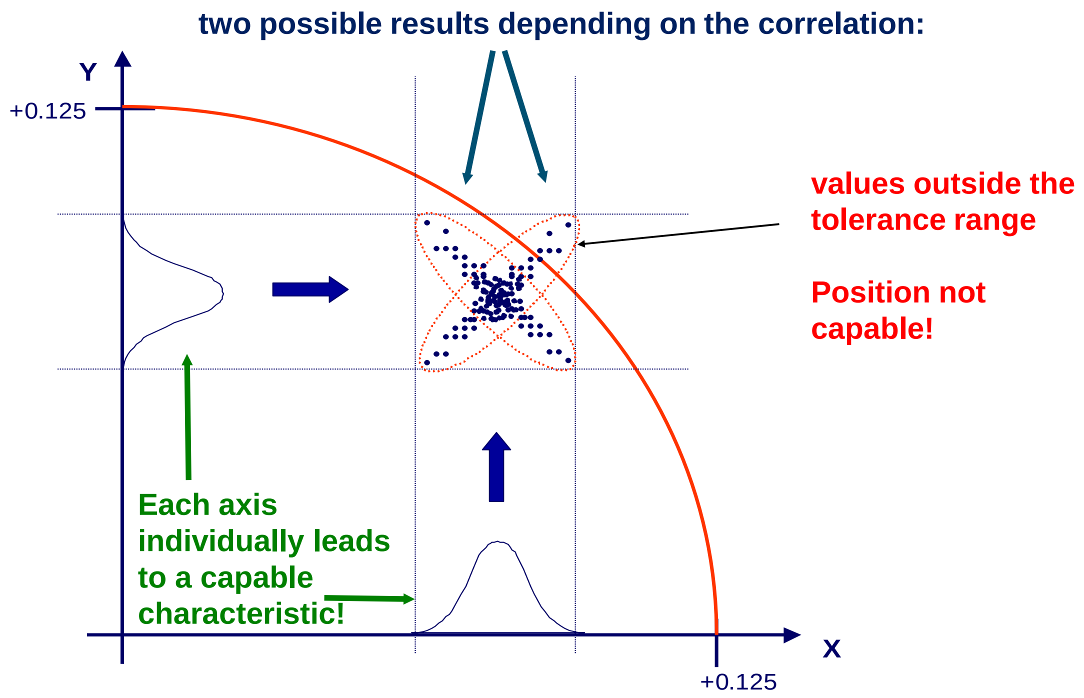
Positional Tolerances – Separate Analysis of the Axes



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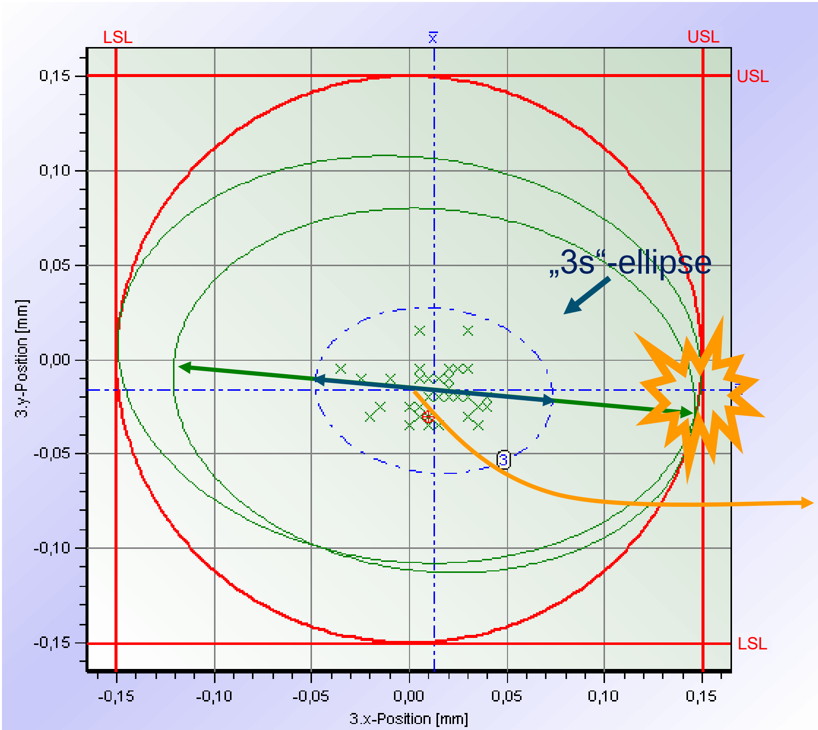
Notes:

Although all values are within specification and considering the axes separately results in two capable features, values may lie outside the tolerance ellipse due to correlation.

Positional Tolerances – x-y Plot



	3.x-Position
$\bar{x}$	0,01263
$\tilde{x}$	0,010
$T_m - \bar{x}$	-0,01263
	3.y-Position
$\bar{x}$	-0,01638
$\tilde{x}$	-0,020
$T_m - \bar{x}$	0,01638
P_o	1,95 ≤ **2,72** ≤ 3,53
P_{ok}	1,70 ≤ **2,42** ≤ 3,14

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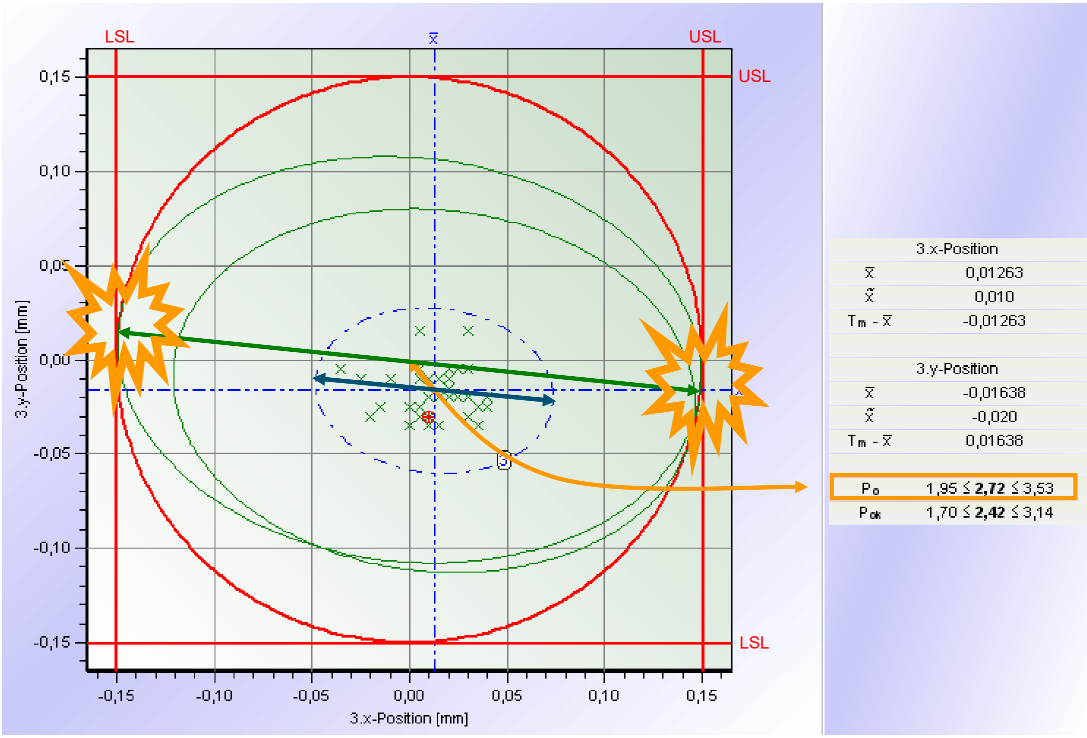
Notes:

Pok describes the maximum size of the scattering ellipse in comparison to the actual scattering ellipse with the position present. Reference value is the 99.73% scattering ellipse analogous to the percentile method

Positional Tolerances – x-y Plot

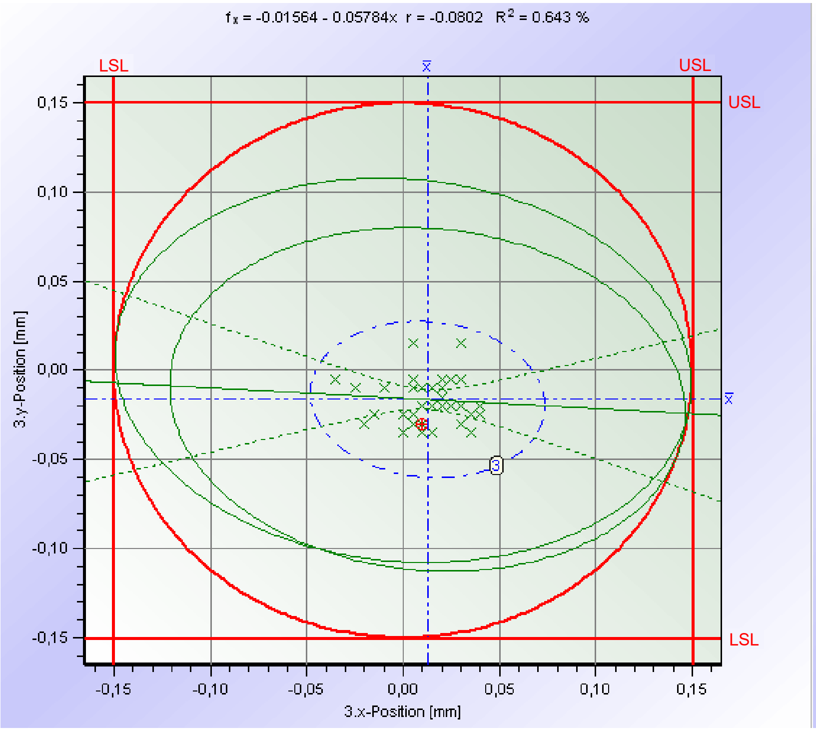


HEXAGON

Notes:

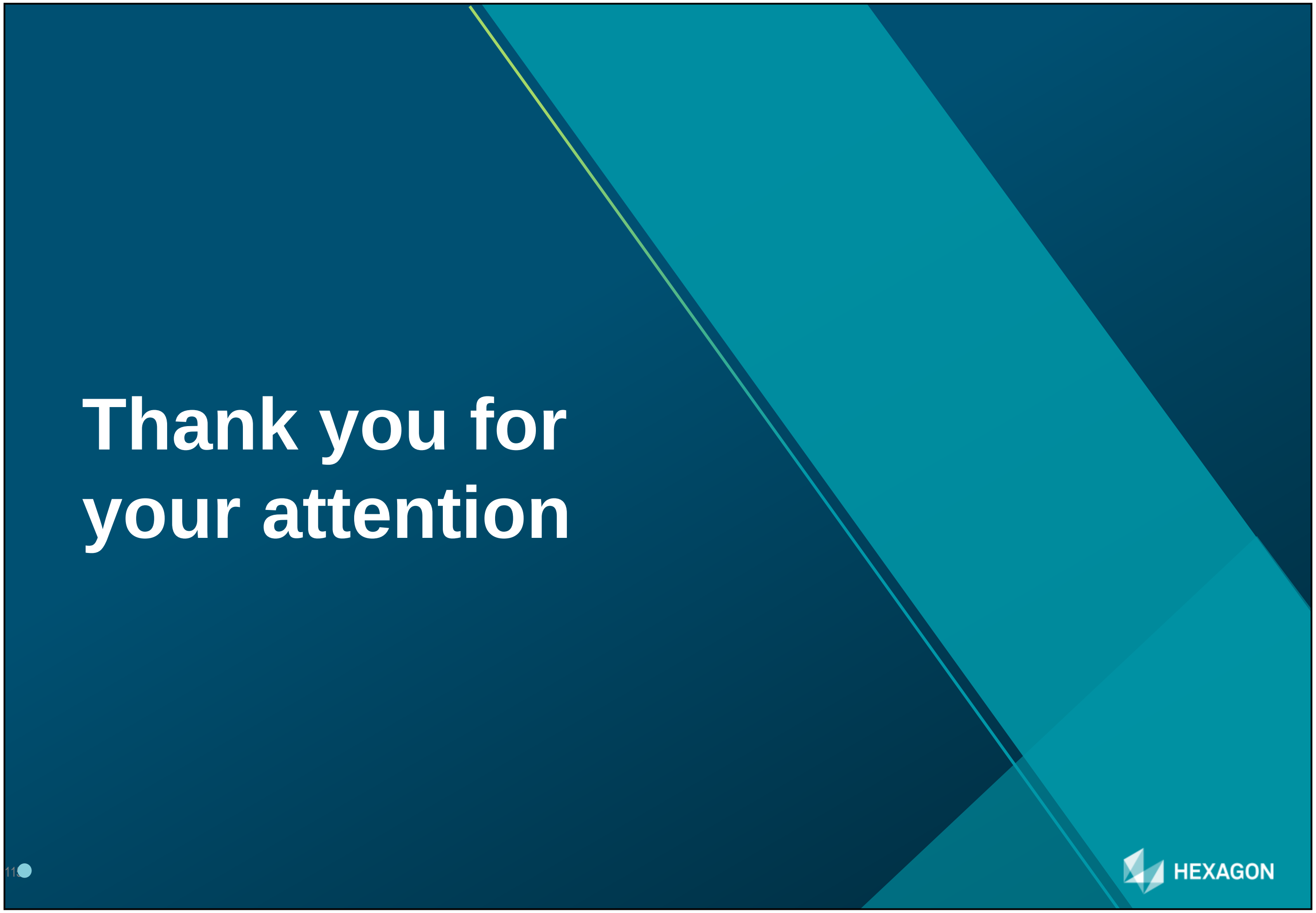
Po describes the maximum size of the scattering ellipse compared to the actual scattering ellipse with optimised position (centre point).Reference value is the 99.73% scattering ellipse analogous to the percentile method

Positional Tolerances – x-y Plot



3.x-Position	
$\bar{x}$	0,01263
$\tilde{x}$	0,010
$T_m - \bar{x}$	-0,01263
3.y-Position	
$\bar{x}$	-0,01638
$\tilde{x}$	-0,020
$T_m - \bar{x}$	0,01638
P_p	1,95 ≤ **2,72** ≤ 3,53
P_{pk}	1,70 ≤ **2,42** ≤ 3,14

Notes:



Notes: