Measurement System Analysis

Learning objectives

- To be able to select and use appropriate methods to verify the .
- To know all the methods, and know how to interpret and evaluate their results
- To know the methods' scope of application as well as their limits
- To know approaches for identifying the causes of non-capable measurement processes and be able to make approval decisions

Seminar agenda

- Definitions and requirements from standards
- Resolution of a display
- Measurement uncertainty of the measurement standard
- Procedure 1 – Systematic error and repeatability
- Procedure 2 – Repeatability and reproducibility
- Procedure 3 – Appraiser-independent systems
- Procedure 4 – Linearity
- Procedure 5 – Stability
- Procedure 6 – Test processes for discretized continuous characteristics
- Procedure 7 – Test processes for discrete characteristics
- Assessment of non-capable measurement and test processes
  - Risk analysis and approval decision
  - Causes of non-capable measurement systems

Done first, for content reasons

Test and measurement

Testing

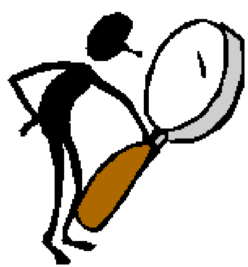
subjectively

objectively

by sensory perception (visual, noise, haptic, …)

by go/no-go gauging

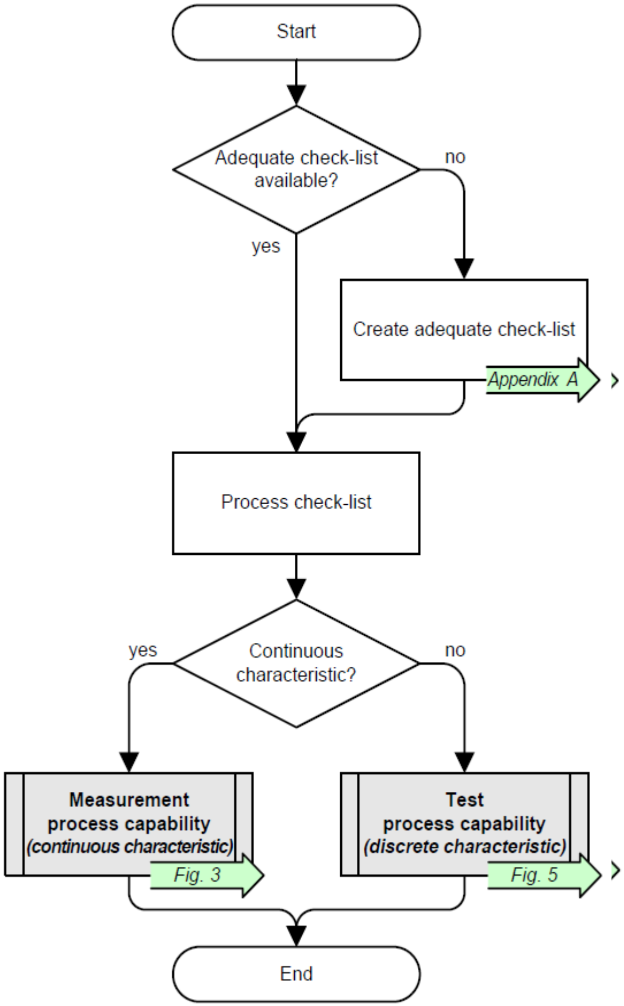
by measuring



Procedure 7 (Type 7 Study)

Procedures 6 / 7 (Type 6 / 7 Studies)

Procedures 1 – 5 (Type 1 - 5 Studies)



Even if you can test by measuring, :

- **Measurement process capability for continuous characteristics**

- **Test process capability for discrete characteristics**

Quote :

Note: **Testing discrete or discretized characteristics is not generally recommended, as meeting today's requirements on the basis of error rates requires unacceptably large sample sizes. The demonstration of capability based on continuous characteristics using procedures 1–5 is always and absolutely preferred.**

Definition: Measurement process and measurement system

- AIAG Core Tool MSA 4th Edition

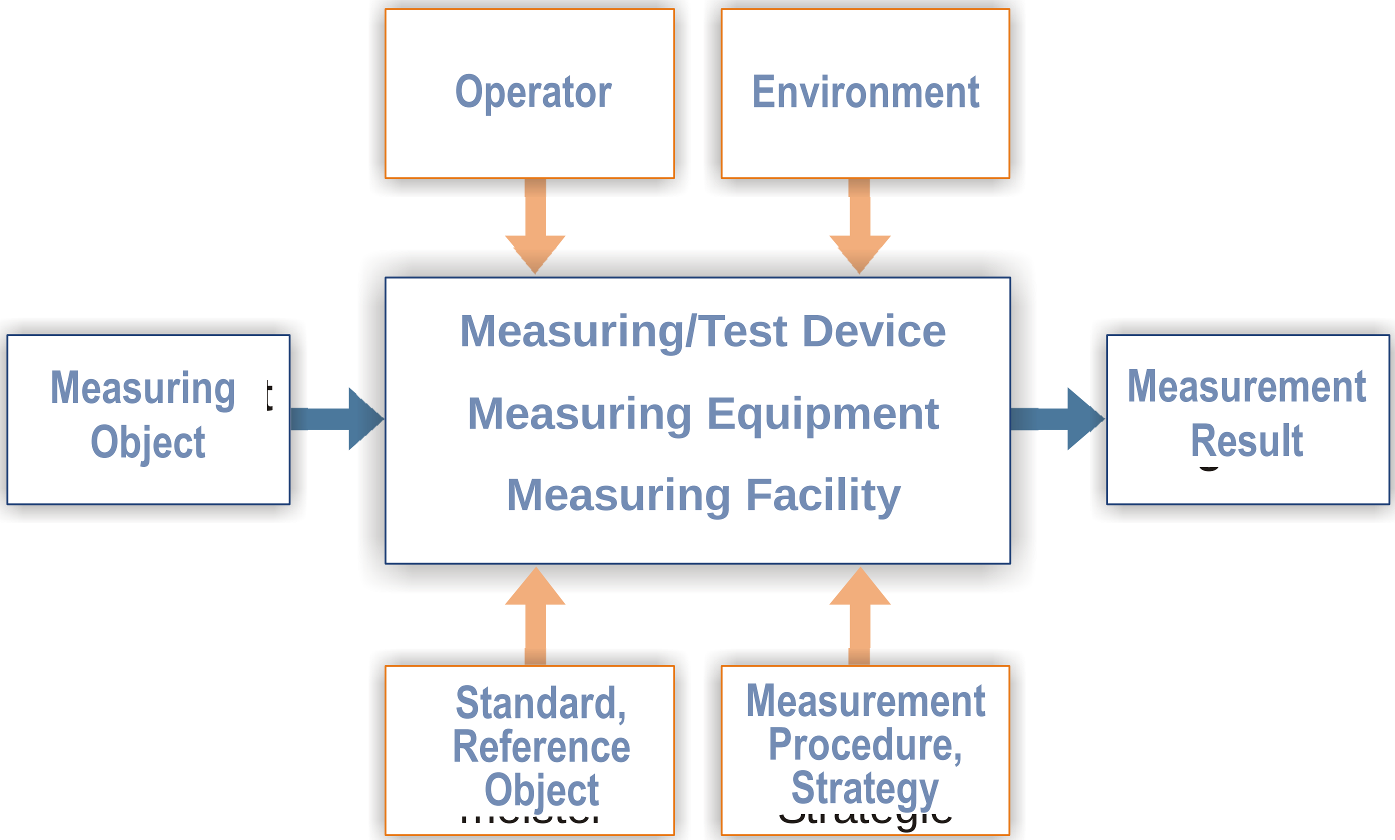
Terminology

Chapter I – Section A
Introduction, Purpose and Terminology

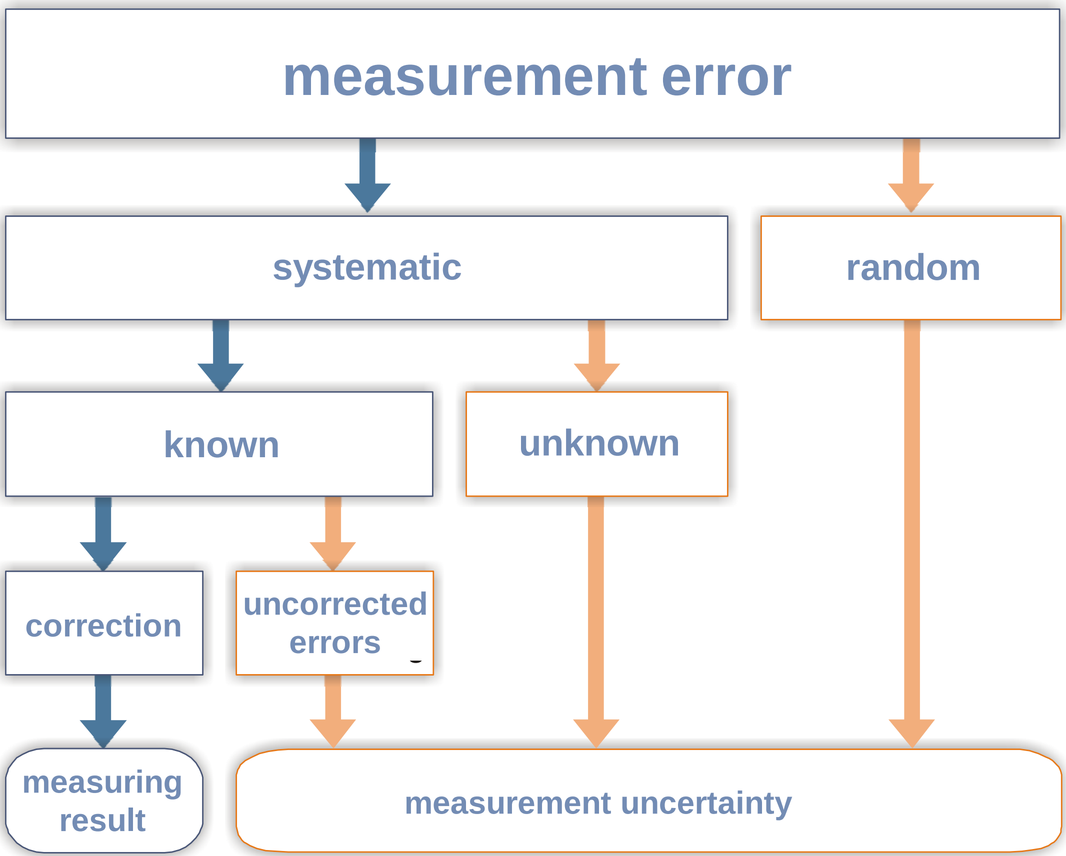
- **Measurement System** is the collection of instruments or gages, standards, operations, methods, fixtures, software, personnel, environment and assumptions used to quantify a unit of measure or fix assessment to the feature characteristic being measured; the complete process used to obtain measurements.

From these definitions it follows that a measurement process may be viewed as a manufacturing process that produces numbers (data) for its output. Viewing a measurement system this way is useful because it allows us to bring to bear all the concepts, philosophy, and tools that have already demonstrated their usefulness in the area of statistical process control.

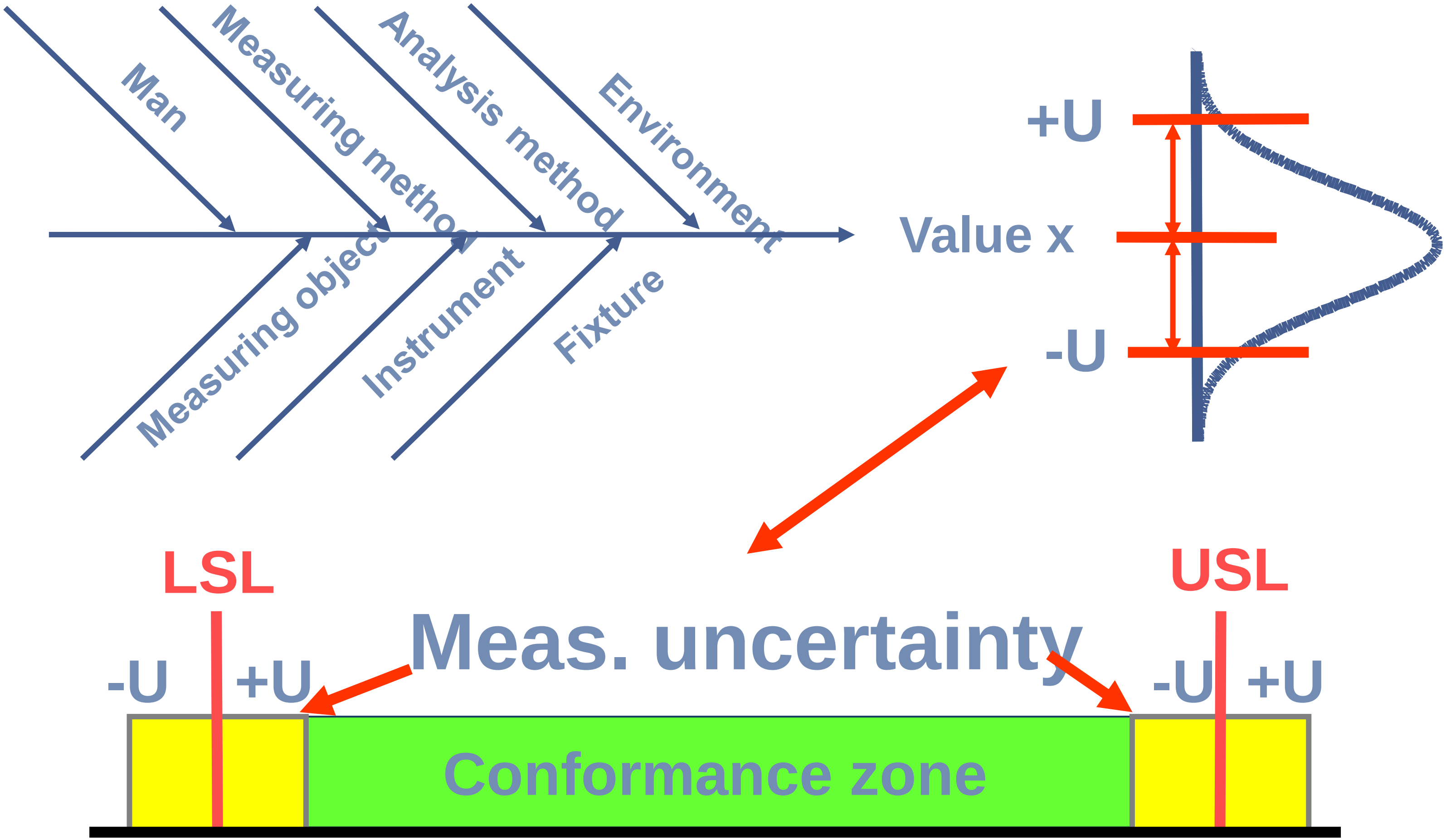
Definition: Measurement process and measurement system



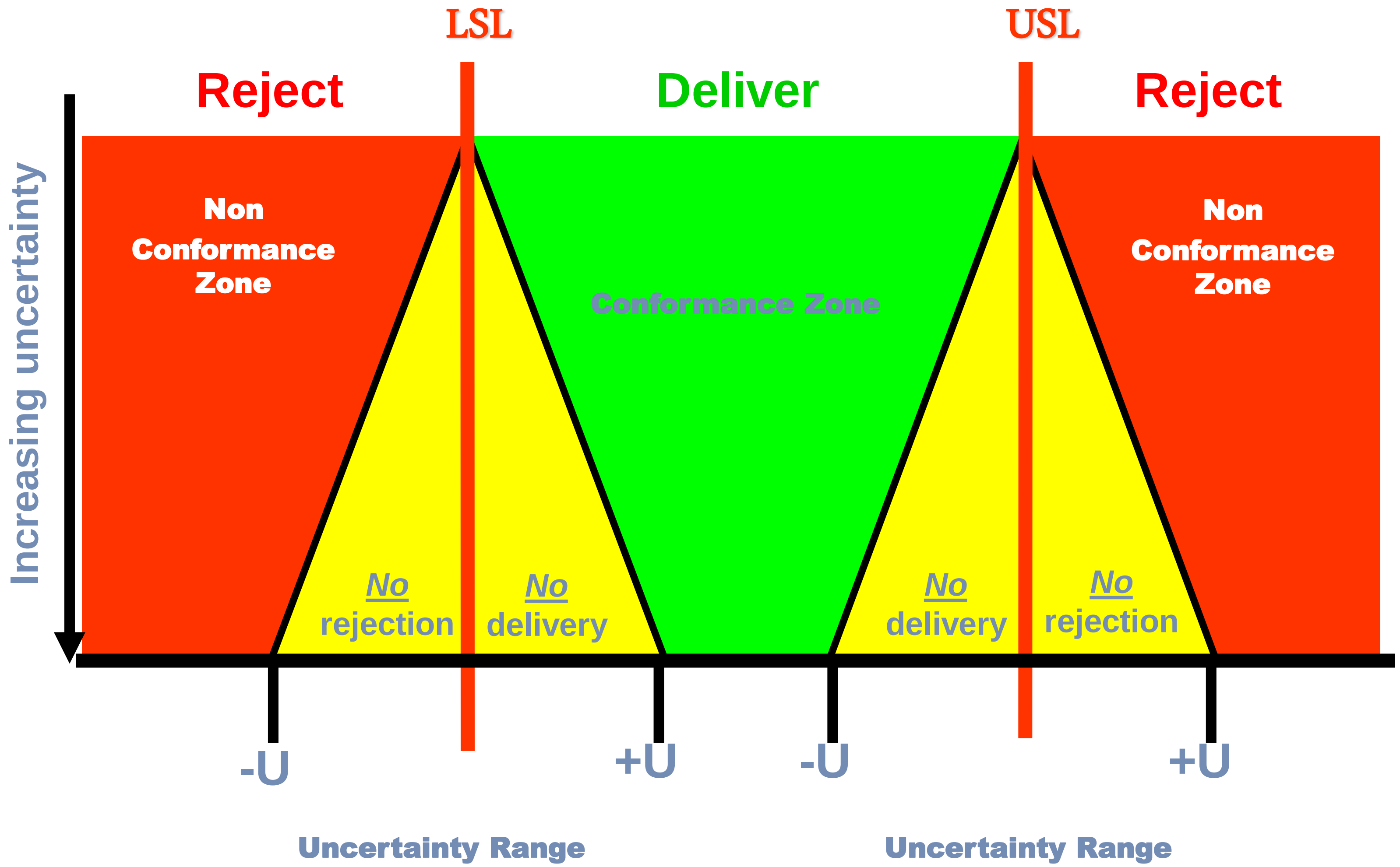
Classification of measurement errors



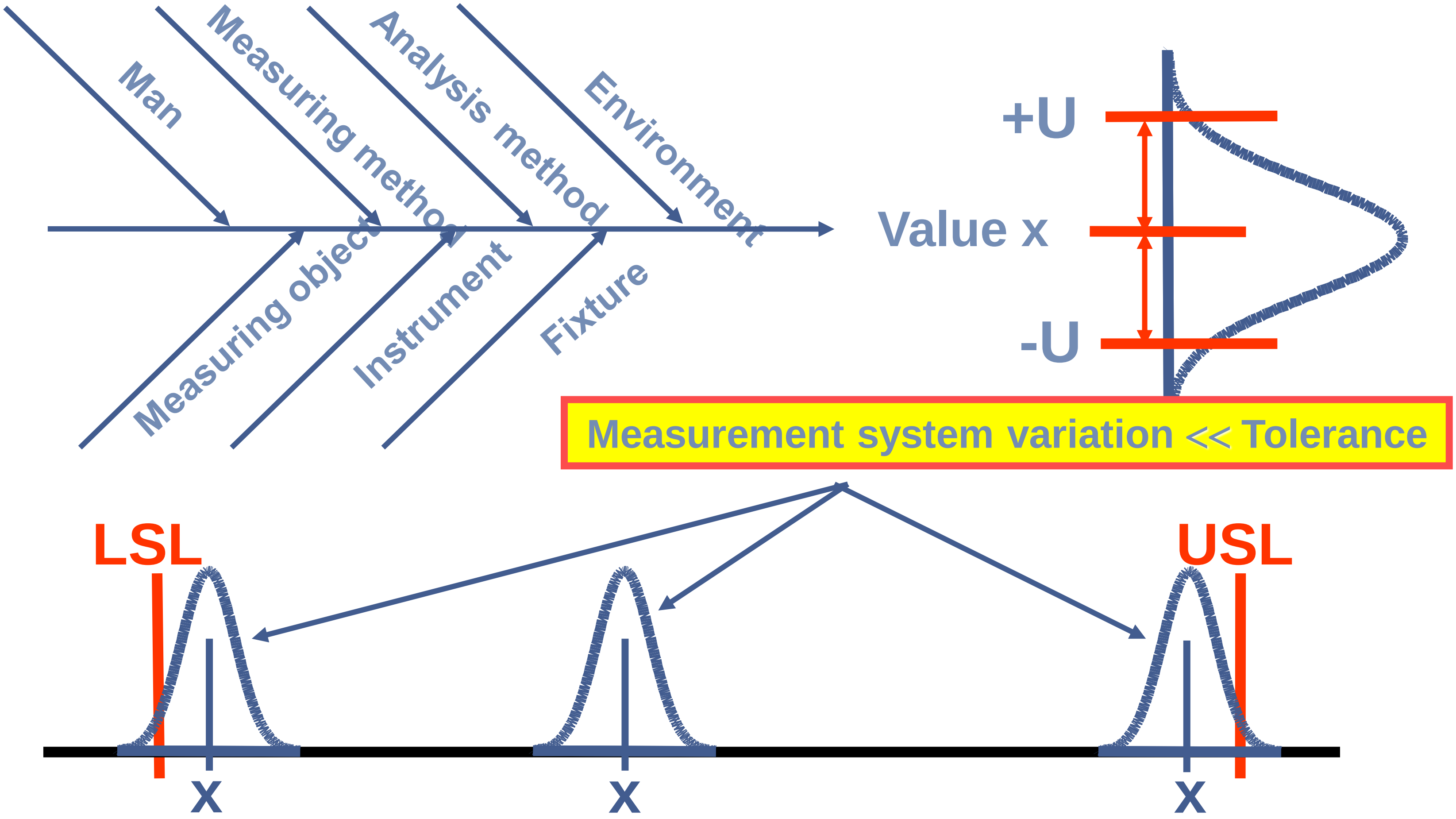
Taking measurement errors into account



ISO 14253 requirement



Taking measurement errors into account



Application

(Quotes:)

- Capability is demonstrated through measurement and tests at the site of operation of the measurement or test equipment and through statistical analyses.
- This makes only sense for measurement and test equipment which (e.g. in the flow of production) performs a sufficiently large number of uniform, repetitive measurements or tests, and only ever applies to the checked characteristic.
- If the same measurement or test equipment is used to perform measurements or tests of different characteristics, capability must be demonstrated again for each new characteristic.
- Where measurement tasks change frequently (e.g. in development and testing areas), determination of measurement uncertainty is preferred to capability.
- Where conformance statements per ISO 14253 are required, determining measurement uncertainty is necessary instead of or in addition to demonstration of capability.
- If there are valid reasons why the methods described cannot be applied, the suitability of other methods should be explored …

Impact of measurement process variation

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

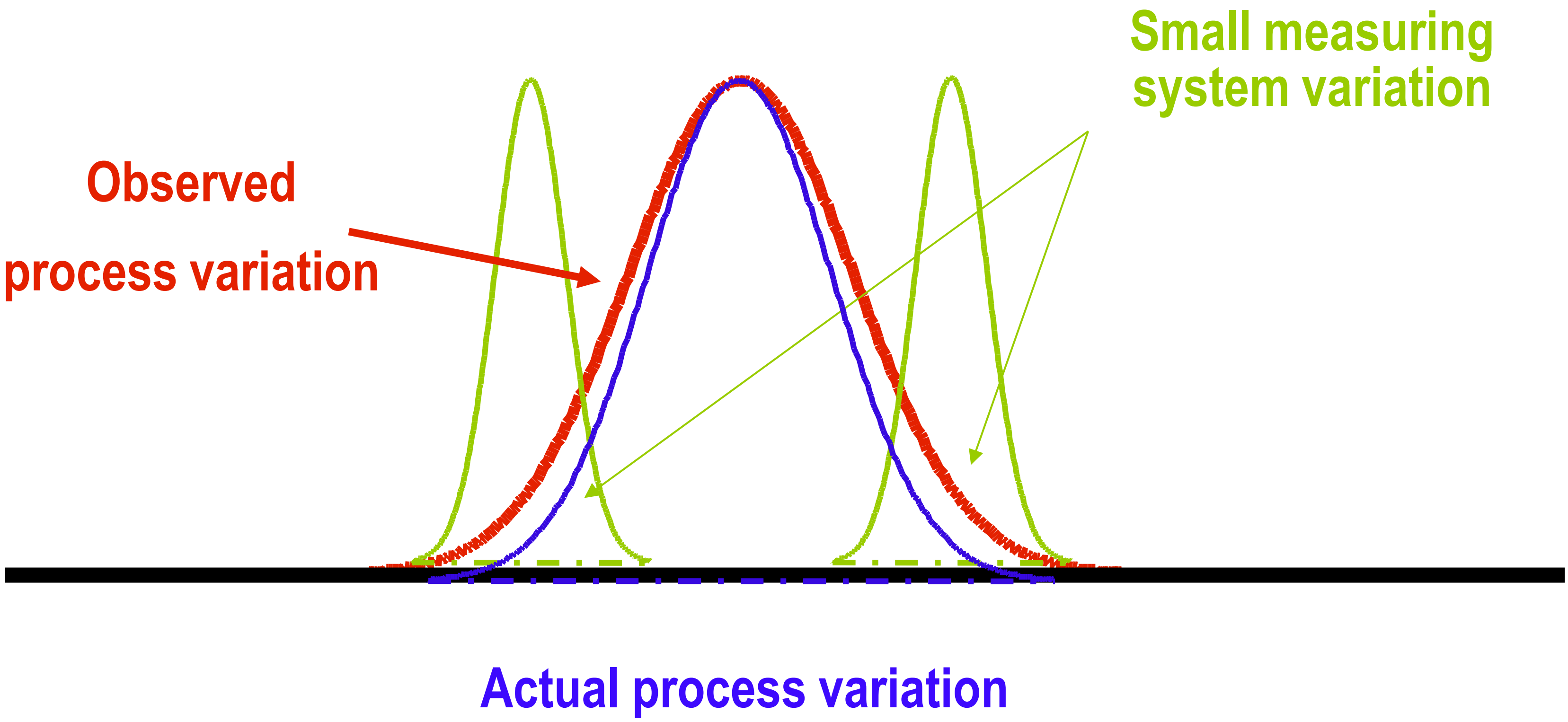
Observed process variation

Actual process variation

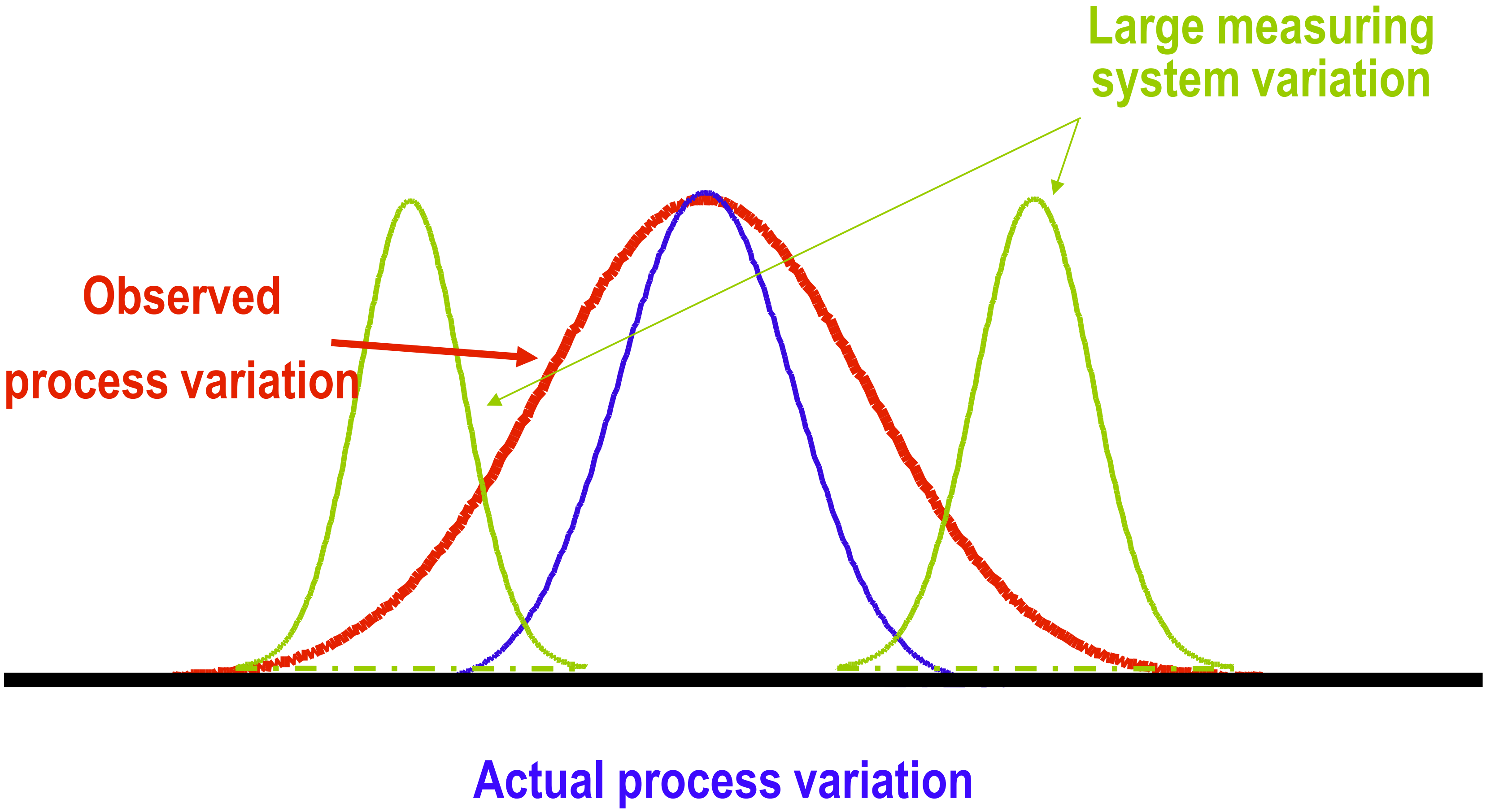
Variation of the measuring system

Impact on process capability!

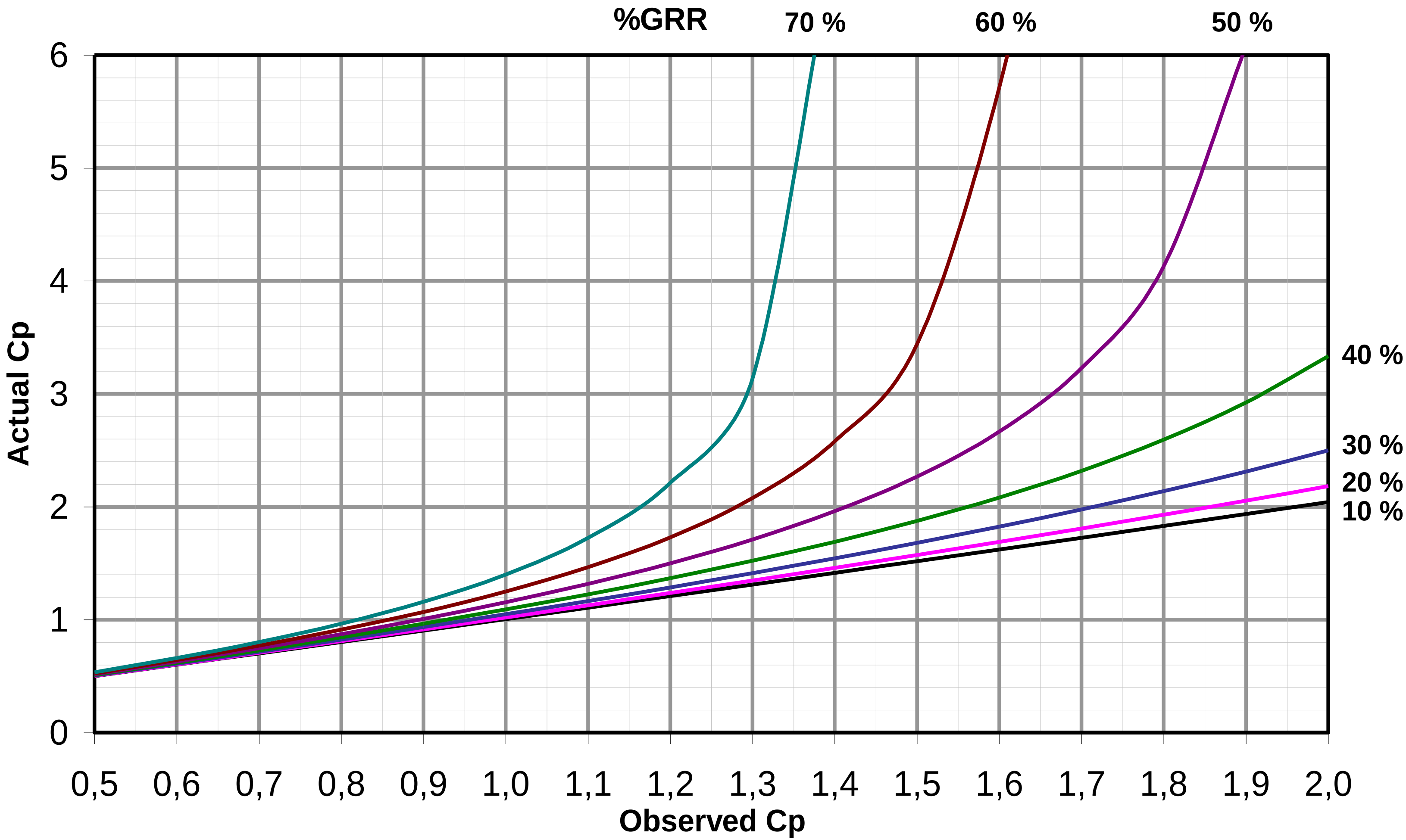
Impact of measurement process variation



Impact of measurement process variation



Impact of measurement process variation



Methods

- Procedure 1 – Measurement of standard/reference - C_g/C_{gk}
  - Prerequisite for procedures 2 to 5
- Procedure 2 – Repeatability and reproducibility - %GRR
  - Influence of real parts and appraisers
- Procedure 3 – Appraiser-independent systems - %GRR
  - Replaces procedure 2 for appraiser-independent systems
- Procedure 4 – Linearity study
  - If not investigated by manufacturer/at calibration
- Procedure 5 – Stability
  - Long-term assessment/monitoring
- Procedure 6 – Discrete characteristics with continuous reference values
  - Determine "grey area" of uncertain decisions as "%GRR"
- Procedure 7 – Discrete characteristics with and without cont. ref. values
  - Assessment using a κ-value (Fleiss' kappa)

Standard methods for approval of variable measuring systems

Methods

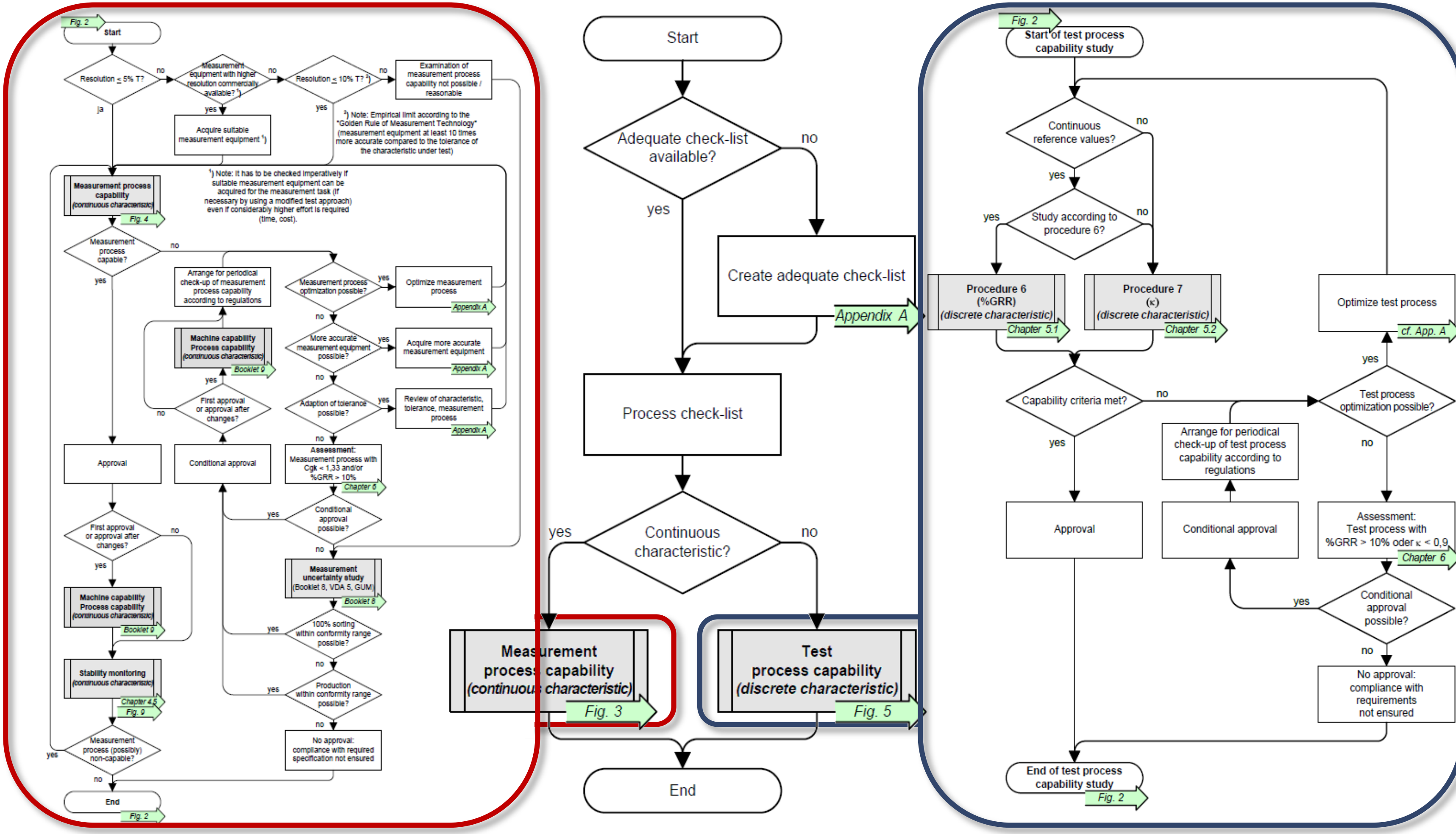
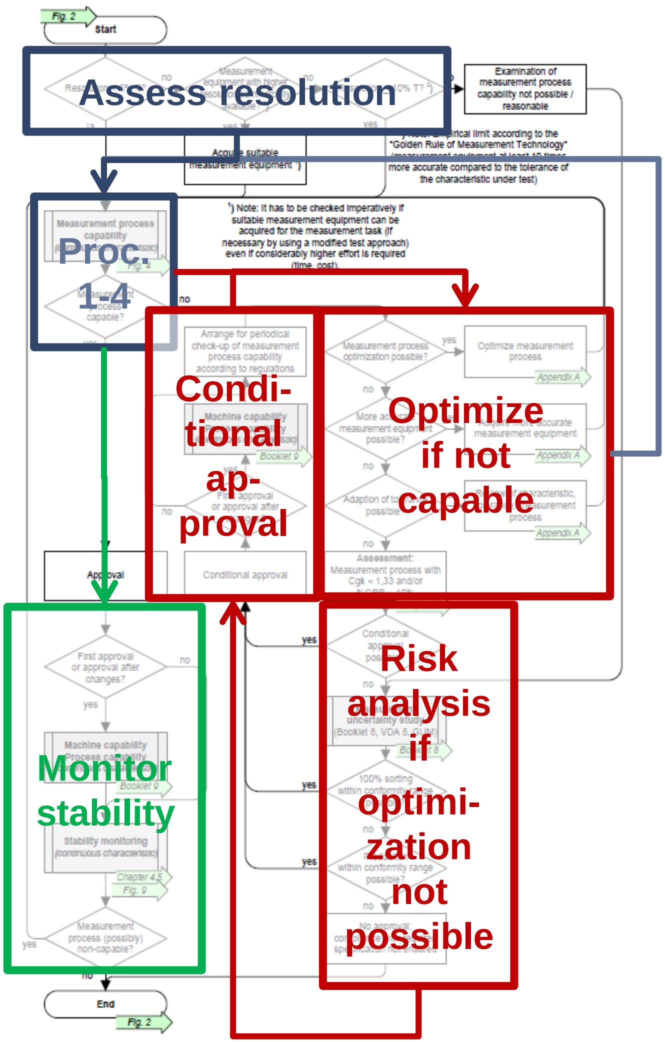


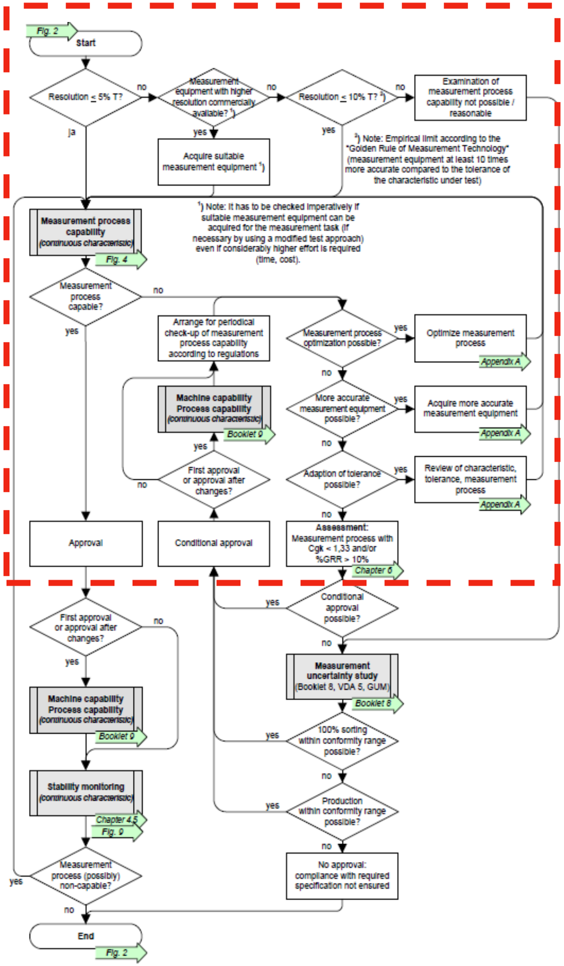
Fig. 2
Start
Resolution ≤ 5% T?
no
Measurement equipment with higher resolution commercially available? [1])
no
Resolution ≤ 10% T? [2])
no
Examination of measurement process capability not possible / reasonable
ja
yes
Acquire suitable measurement equipment [1])
yes
[2]) Note: Empirical limit according to the "Golden Rule of Measurement Technology" (measurement equipment at least 10 times more accurate compared to the tolerance of the characteristic under test)
[1]) Note: It has to be checked imperatively if suitable measurement equipment can be acquired for the measurement task (if necessary by using a modified test approach) even if considerably higher effort is required (time, cost).
Measurement process capability (continuous characteristic)
Fig. 4
Measurement process capable?
no
yes
Arrange for periodical check-up of measurement process capability according to regulations
Measurement process optimization possible?
yes
Optimize measurement process
Appendix A
Machine capability Process capability (continuous characteristic)
Booklet 9
More accurate measurement equipment possible?
yes
Acquire more accurate measurement equipment
Appendix A
First approval or approval after changes?
Adaption of tolerance possible?
Review of characteristic, tolerance, measurement process
Appendix A
Approval
Conditional approval
Assessment: Measurement process with Cgk < 1,33 and/or %GRR > 10%
Chapter 6
Conditional approval possible?
First approval or approval after changes?
Measurement uncertainty study (Booklet 8, VDA 5, GUM)
Booklet 8
Machine capability Process capability (continuous characteristic)
Booklet 9
100% sorting within conformity range possible?
Stability monitoring (continuous characteristic)
Chapter 4.5
Fig. 9
Production within conformity range possible?
Measurement process (possibly) non-capable?
No approval: compliance with required specification not ensured
End
Fig. 2
Start
Adequate check-list available?
no
yes
Create adequate check-list
Appendix A
Process check-list
Continuous characteristic?
yes
no
Measurement process capability (continuous characteristic)
Fig. 3
Test process capability (discrete characteristic)
Fig. 5
End
Fig. 2
Start of test process capability study
Continuous reference values?
no
yes
Study according to procedure 6?
yes
no
Procedure 6 (%GRR) (discrete characteristic)
Chapter 5.1
Procedure 7 (κ) (discrete characteristic)
Chapter 5.2
Optimize test process
cf. App. A
Capability criteria met?
no
yes
Test process optimization possible?
Arrange for periodical check-up of test process capability according to regulations
Approval
Conditional approval
Assessment: Test process with %GRR > 10% oder κ < 0,9
Chapter 6
Conditional approval possible?
No approval: compliance with requirements not ensured
End of test process capability study
Fig. 2

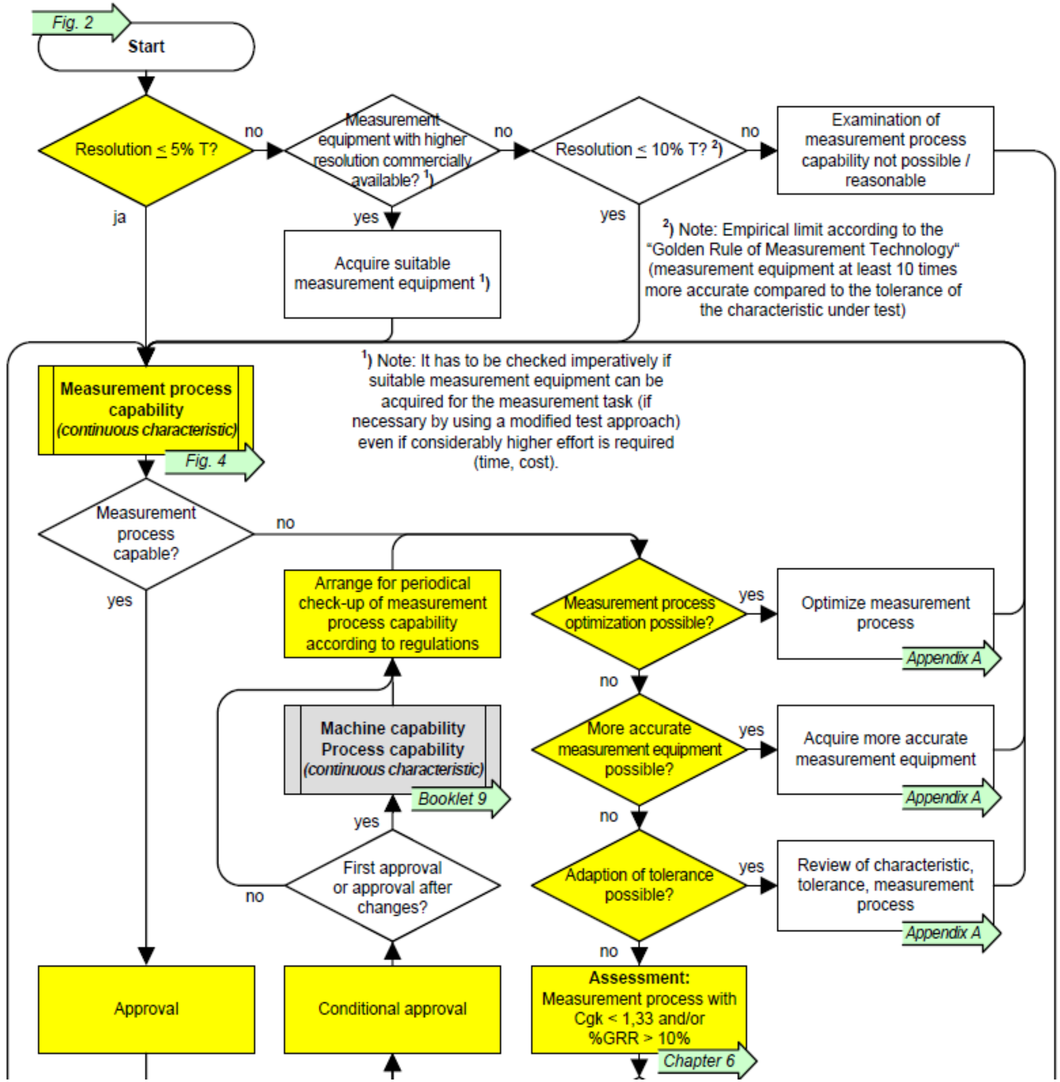
Flow chart
Measurement processes

- Assess resolution
- Perform capability analyses
- If capable: use measurement systems and monitor stability
- If not capable:
  - Optimize
  - Risk analysis
  - Conditional approval and re-qualification



Flow chart





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Measurement process capability (continuous characteristic)
Fig. 4
[1]) Note: It has to be checked imperatively if suitable measurement equipment can be acquired for the measurement task (if necessary by using a modified test approach) even if considerably higher effort is required (time, cost).
Measurement process capable?
no
yes
Arrange for periodical check-up of measurement process capability according to regulations
Measurement process optimization possible?
yes
Optimize measurement process
Appendix A
no
Machine capability Process capability (continuous characteristic)
Booklet 9
More accurate measurement equipment possible?
yes
Acquire more accurate measurement equipment
Appendix A
yes
no
First approval or approval after changes?
no
Adaption of tolerance possible?
yes
Review of characteristic, tolerance, measurement process
Appendix A
no
Approval
Conditional approval
Assessment: Measurement process with Cgk < 1,33 and/or %GRR > 10%
Chapter 6

Flow chart

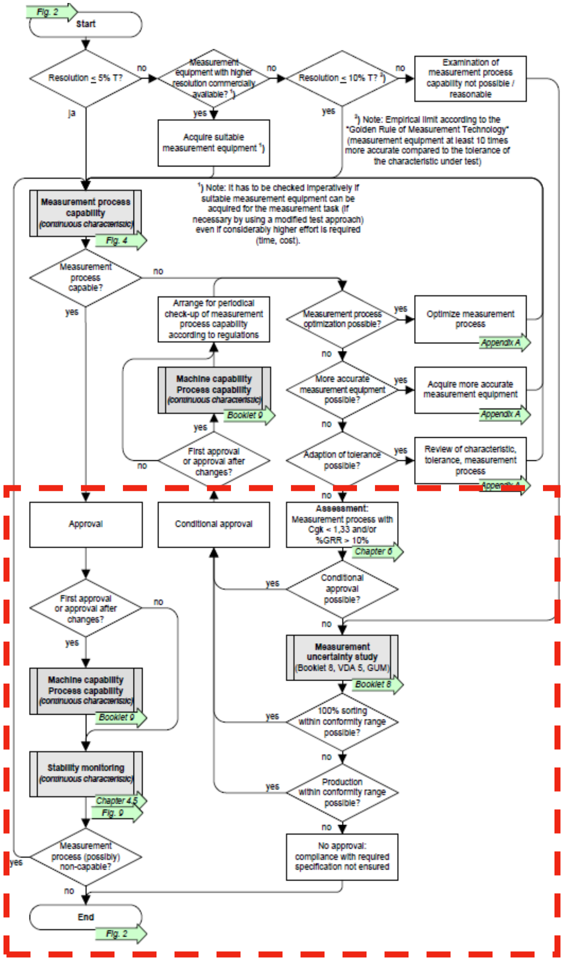
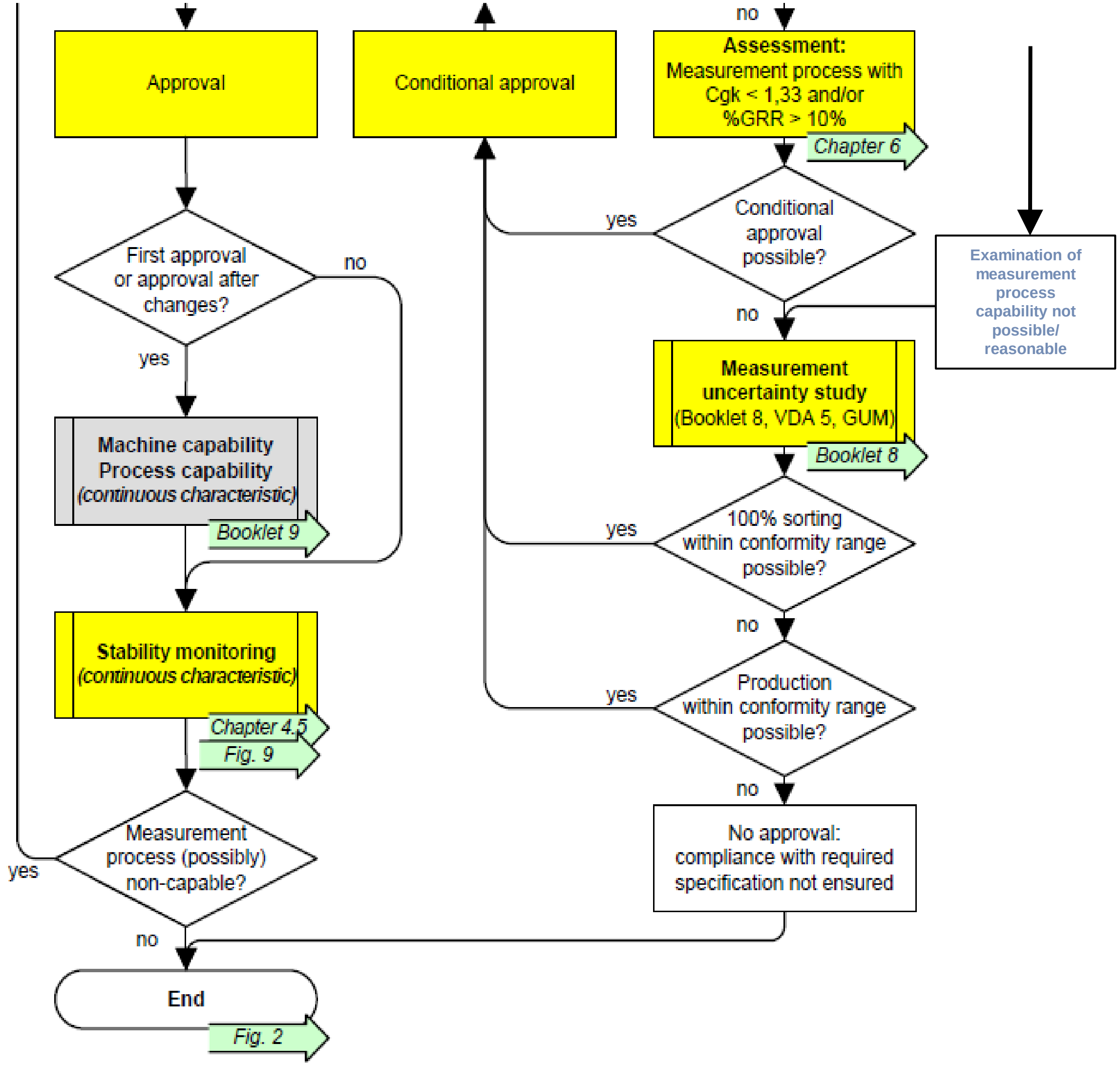


Fig. 2
Start
Resolution ≤ 5% T?
Measurement equipment with higher resolution commercially available?
Resolution ≤ 10% T?
Examination of measurement process capability not possible / reasonable
Acquire suitable measurement equipment
Measurement process capability (continuous characteristic)
Fig. 4
Measurement process capable?
Arrange for periodical check-up of measurement process capability according to regulations
Measurement process optimization possible?
Optimize measurement process
Appendix A
More accurate measurement equipment possible?
Acquire more accurate measurement equipment
Adaption of tolerance possible?
Review of characteristic, tolerance, measurement process
Machine capability
Process capability
Booklet 9
First approval or approval after changes?
Approval
Conditional approval
Assessment:
Measurement process with Cgk < 1,33 and/or %GRR > 10%
Chapter 6
Conditional approval possible?
Measurement uncertainty study (Booklet 8, VDA 5, GUM)
Booklet 8
100% sorting within conformity range possible?
Production within conformity range possible?
Stability monitoring (continuous characteristic)
Chapter 4.5
Fig. 9
Measurement process (possibly) non-capable?
No approval: compliance with required specification not ensured
End
Fig. 2
yes
no
ja



Approval
Conditional approval
no
Assessment:
Measurement process with Cgk < 1,33 and/or %GRR > 10%
Chapter 6
First approval or approval after changes?
no
yes
Conditional approval possible?
yes
no
Examination of measurement process capability not possible/ reasonable
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Booklet 8
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Process capability
(continuous characteristic)
Booklet 9
100% sorting within conformity range possible?
yes
no
Stability monitoring
(continuous characteristic)
Chapter 4.5
Fig. 9
Production within conformity range possible?
yes
no
yes
Measurement process (possibly) non-capable?
No approval: compliance with required specification not ensured
no
End
Fig. 2

Starting point of a measurement system analysis

- Purchase of a new measurement system
- New application of an existing measurement system
  - New products
  - New characteristics
  - New measurement strategies
  - …
- Revision of a measurement system
  - Regular maintenance
  - Repair
  - Expansion/change of a system
  - …
- Viewed as a study of a measurement “process” – whenever something might have changed about a process parameter/variable

Flow chart

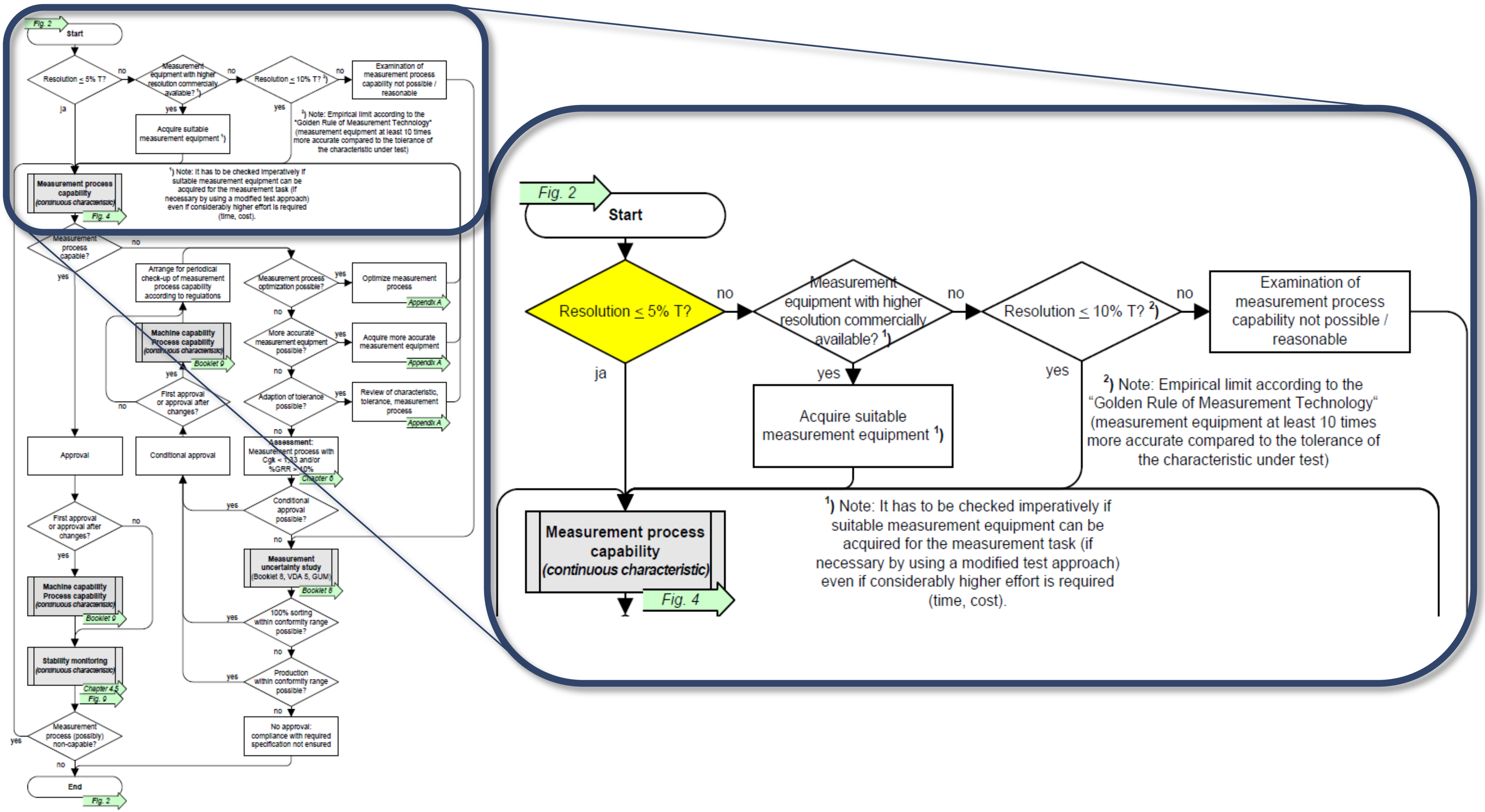

Fig. 2
Start
Resolution ≤ 5% T?
no
Measurement equipment with higher resolution commercially available? 1)
no
Resolution ≤ 10% T? 2)
no
Examination of measurement process capability not possible / reasonable
ja
yes
yes
Acquire suitable measurement equipment 1)
2) Note: Empirical limit according to the "Golden Rule of Measurement Technology" (measurement equipment at least 10 times more accurate compared to the tolerance of the characteristic under test)
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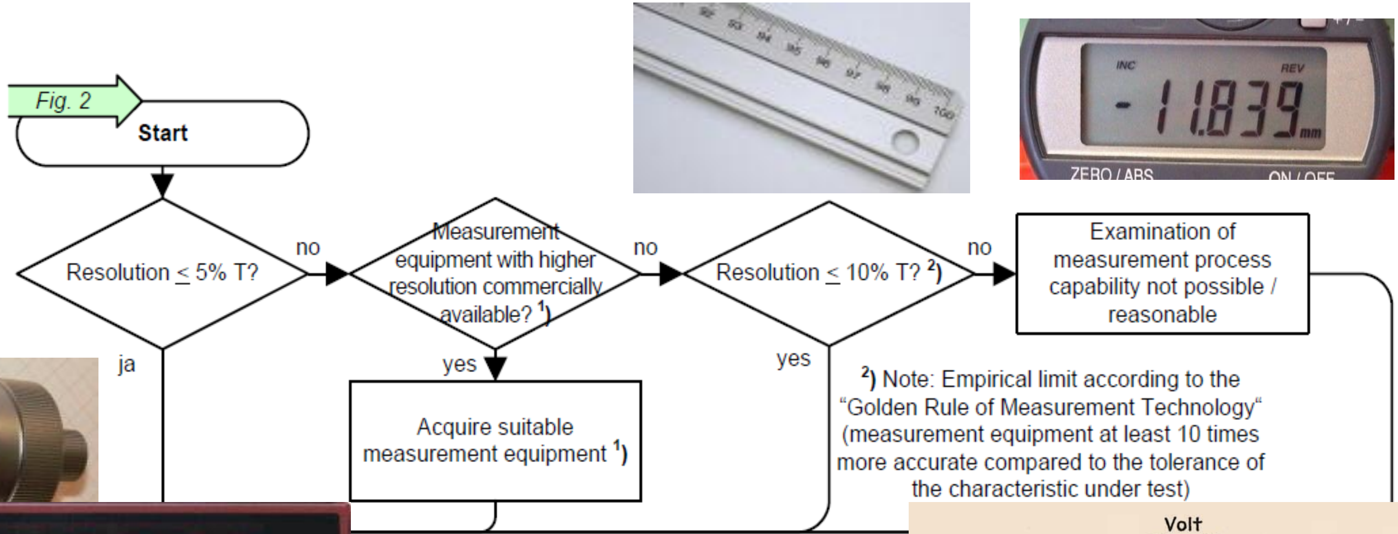
Measurement process capability (continuous characteristic)
Fig. 4



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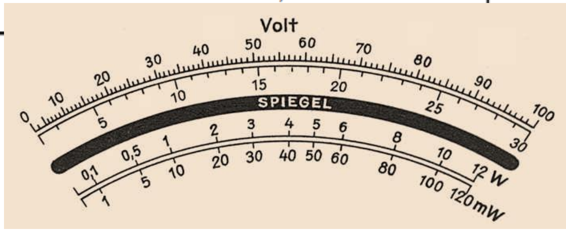

Resolution: the smallest change in a measured characteristic that causes a noticeable change in the relevant display [VIM, 4.14]
Resolution of a display: the smallest difference between indicated values that can be meaningfully distinguished [VIM, 4.15]

Flow chart

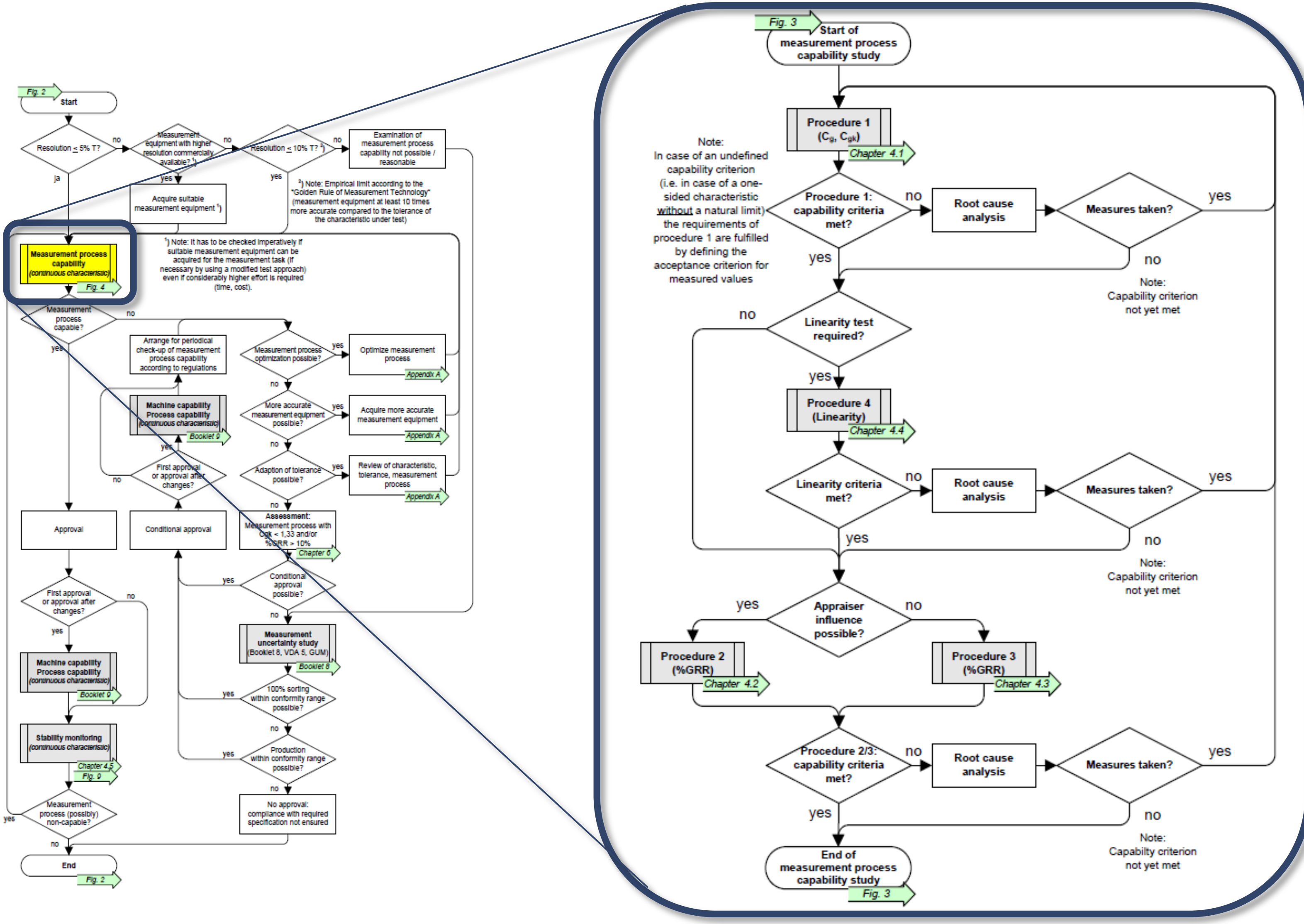

Fig. 2
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Resolution ≤ 5% T?
no
Measurement equipment with higher resolution commercially available? [1]
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Resolution ≤ 10% T? [2]
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Measurement process capability (continuous characteristic)
Fig. 4
Measurement process capable?
no
yes
Arrange for periodical check-up of measurement process capability according to regulations
Measurement process optimization possible?
yes
Optimize measurement process
Appendix A
no
Machine capability Process capability (continuous characteristic)
Booklet 9
More accurate measurement equipment possible?
yes
Acquire more accurate measurement equipment
Appendix A
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First approval or approval after changes?
Adaption of tolerance possible?
yes
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100% sorting within conformity range possible?
Stability monitoring (continuous characteristic)
Chapter 4.5
Fig. 9
Production within conformity range possible?
Measurement process (possibly) non-capable?
No approval: compliance with required specification not ensured
End
Fig. 2
Fig. 3
Start of measurement process capability study
Procedure 1 (C_g, C_{gk})
Chapter 4.1
Note:
In case of an undefined capability criterion (i.e. in case of a one-sided characteristic without a natural limit) the requirements of procedure 1 are fulfilled by defining the acceptance criterion for measured values
Procedure 1: capability criteria met?
no
Root cause analysis
Measures taken?
yes
yes
no
Note: Capability criterion not yet met
no
Linearity test required?
yes
Procedure 4 (Linearity)
Chapter 4.4
Linearity criteria met?
no
Root cause analysis
Measures taken?
yes
yes
no
Note: Capability criterion not yet met
yes
Appraiser influence possible?
no
Procedure 2 (%GRR)
Chapter 4.2
Procedure 3 (%GRR)
Chapter 4.3
Procedure 2/3: capability criteria met?
no
Root cause analysis
Measures taken?
yes
yes
no
Note: Capabilty criterion not yet met
End of measurement process capability study
Fig. 3

Flow chart

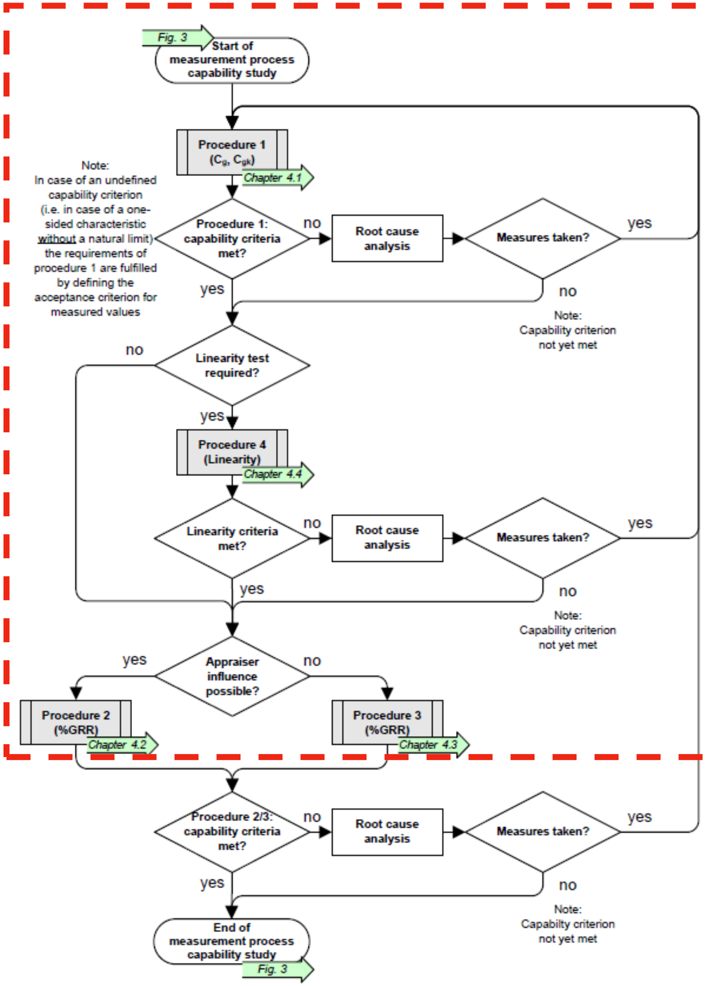


Fig. 3
Start of measurement process capability study
Procedure 1 (C_g, C_{gk})
Chapter 4.1
Note: In case of an undefined capability criterion (i.e. in case of a one-sided characteristic without a natural limit) the requirements of procedure 1 are fulfilled by defining the acceptance criterion for measured values
Procedure 1: capability criteria met?
no
Root cause analysis
Measures taken?
yes
no
Note: Capability criterion not yet met
yes
Linearity test required?
no
yes
Procedure 4 (Linearity)
Chapter 4.4
Linearity criteria met?
no
Root cause analysis
Measures taken?
yes
no
Note: Capability criterion not yet met
yes
Appraiser influence possible?
yes
no
Procedure 2 (%GRR)
Chapter 4.2
Procedure 3 (%GRR)
Chapter 4.3
Procedure 2/3: capability criteria met?
no
Root cause analysis
Measures taken?
yes
no
Note: Capabilty criterion not yet met
yes
End of measurement process capability study
Fig. 3

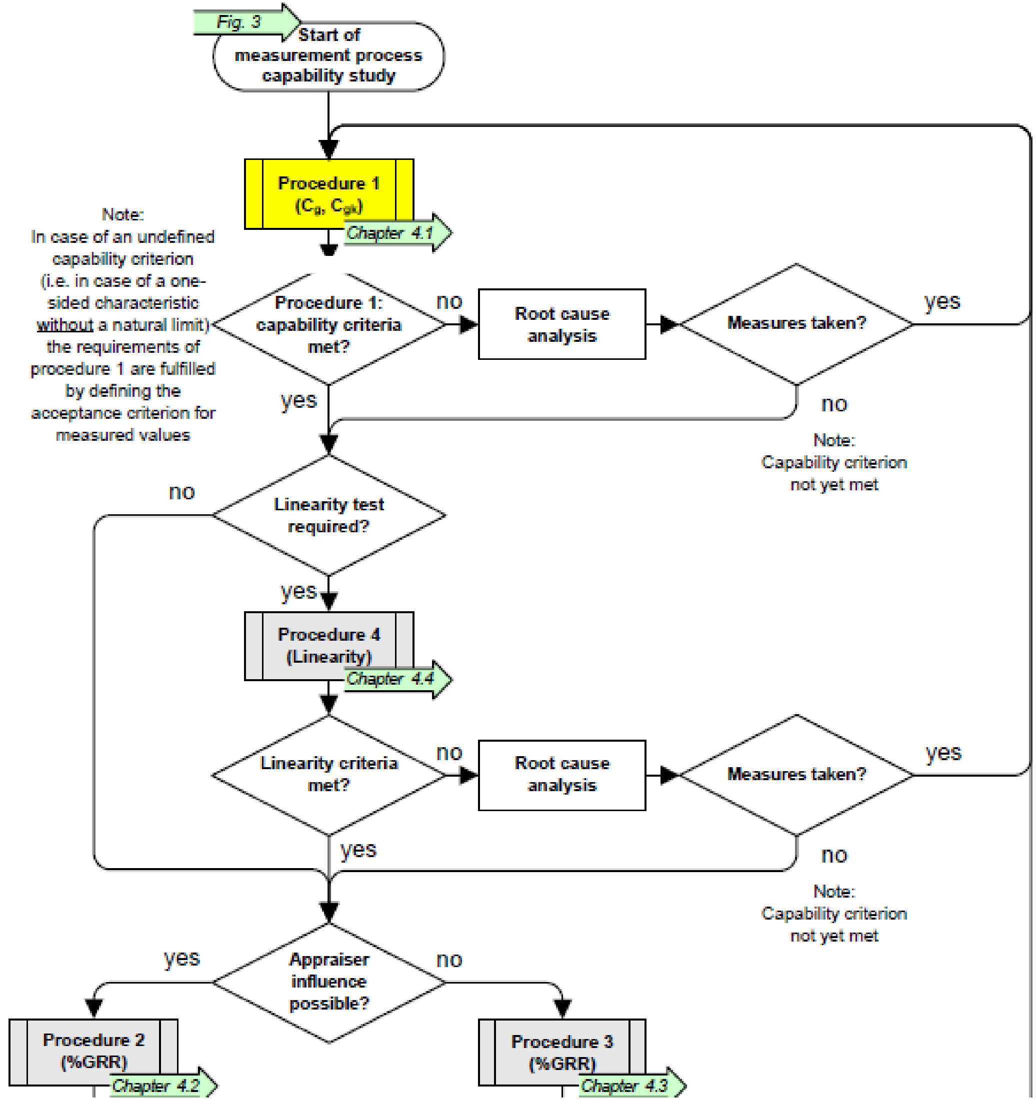


Fig. 3
Start of measurement process capability study
Procedure 1 (C_g, C_{gk})
Chapter 4.1
Note: In case of an undefined capability criterion (i.e. in case of a one-sided characteristic without a natural limit) the requirements of procedure 1 are fulfilled by defining the acceptance criterion for measured values
Procedure 1: capability criteria met?
no
Root cause analysis
Measures taken?
yes
no
Note: Capability criterion not yet met
yes
Linearity test required?
no
yes
Procedure 4 (Linearity)
Chapter 4.4
Linearity criteria met?
no
Root cause analysis
Measures taken?
yes
no
Note: Capability criterion not yet met
yes
Appraiser influence possible?
yes
no
Procedure 2 (%GRR)
Chapter 4.2
Procedure 3 (%GRR)
Chapter 4.3

Procedure 1 – Using a measurement standard

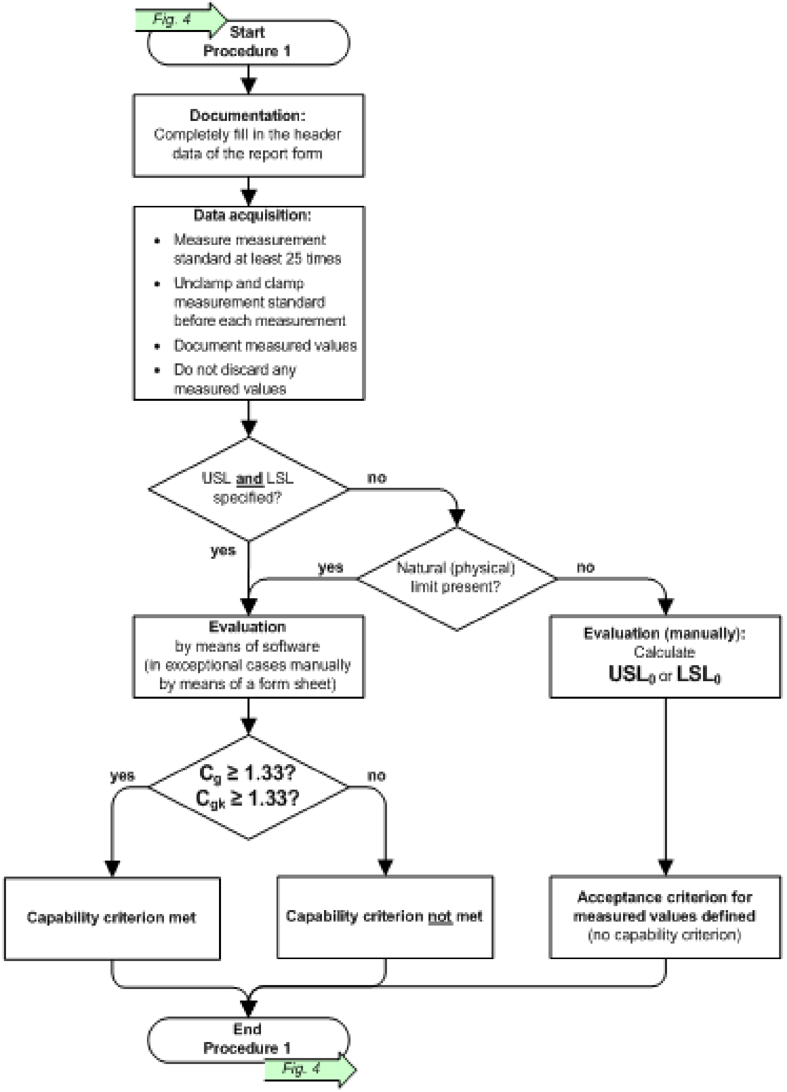
- Objective
  To demonstrate the capability of a measurement process (as a test process for a certain characteristic) in terms of the location and variation of measured values within the characteristic's tolerance region.

- Requirements
  - Product characteristics with a bilateral tolerance
  - If there is a natural limit, this is used as a replacement (e.g. gap width, roughness, evenness … USL is defined, LSL* = 0)
  - Calibrated measurement standard (reference part) available

- Conducting the study
  - The standard is measured 50 times (min. 25 times) under repeatability conditions

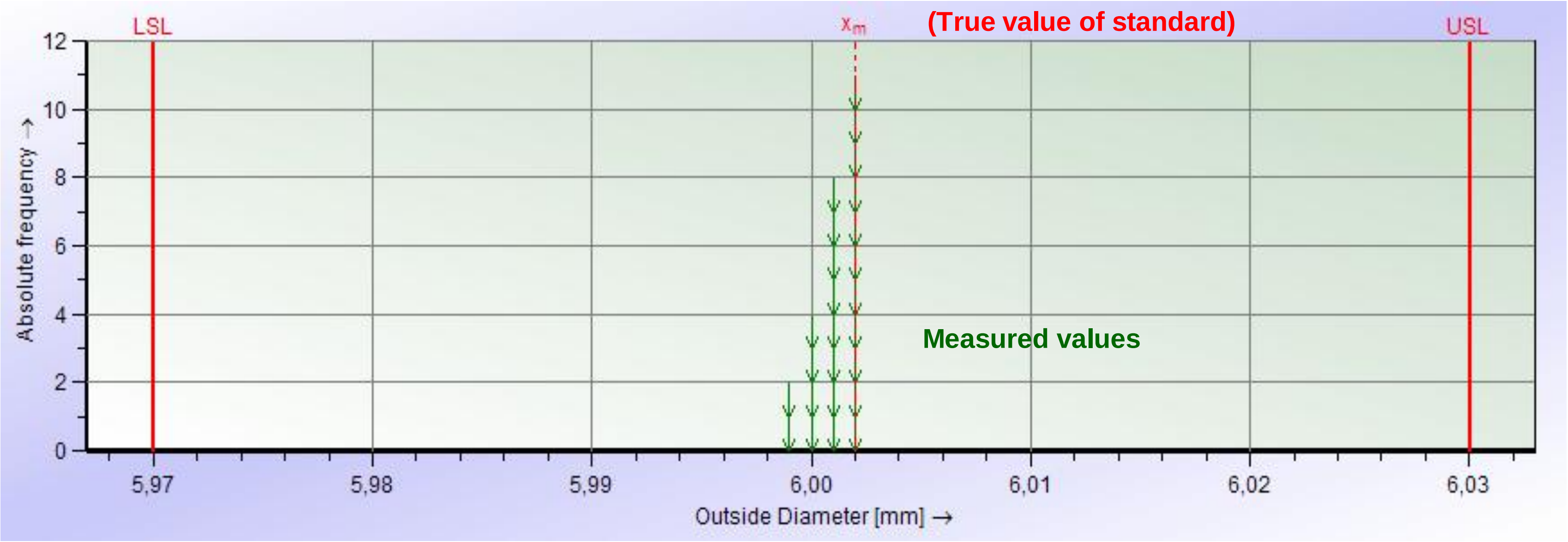
Procedure 1 – Process

- Documentation
- Data collection
- If T or T* (natural limit) is defined
  - Calculate capability indices
  - Assess capability indices (C_g, C_{gk} ≥ 1.33)
- If T is not defined
  - Calculate critical limits USL_0/LSL_0
  - Define acceptance criterion for measured values



Procedure 1 – Data collection

- Typically 50 (min. 25) measurements
  - of a measurement standard
  - under repeatability conditions
- Defined measurement point on the standard
- Replace standard after each measurement (reinsert, reclamp, recontact)



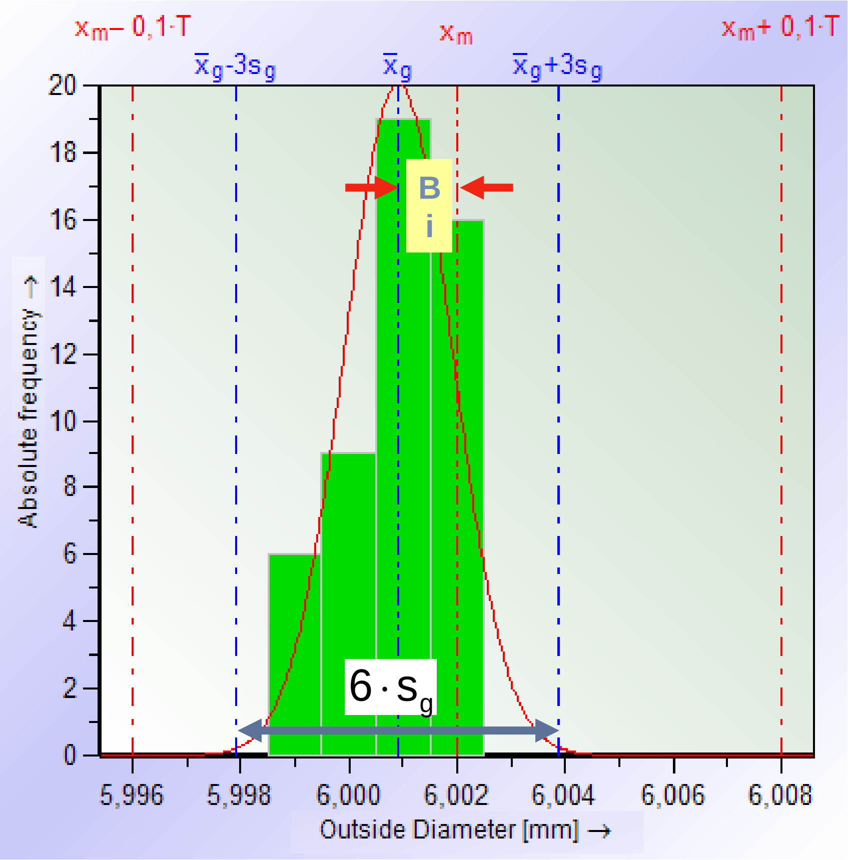
Bias $Bi = \bar{x}_g - x_m$

Spread $6\,s_g$

Remember:

✓ **Mean** $\bar{x}_g = \frac{\sum x_i}{n}$

✓ **Standard deviation** $s_g = \sqrt{\frac{\sum(\bar{x}-x_i)^2}{n-1}}$

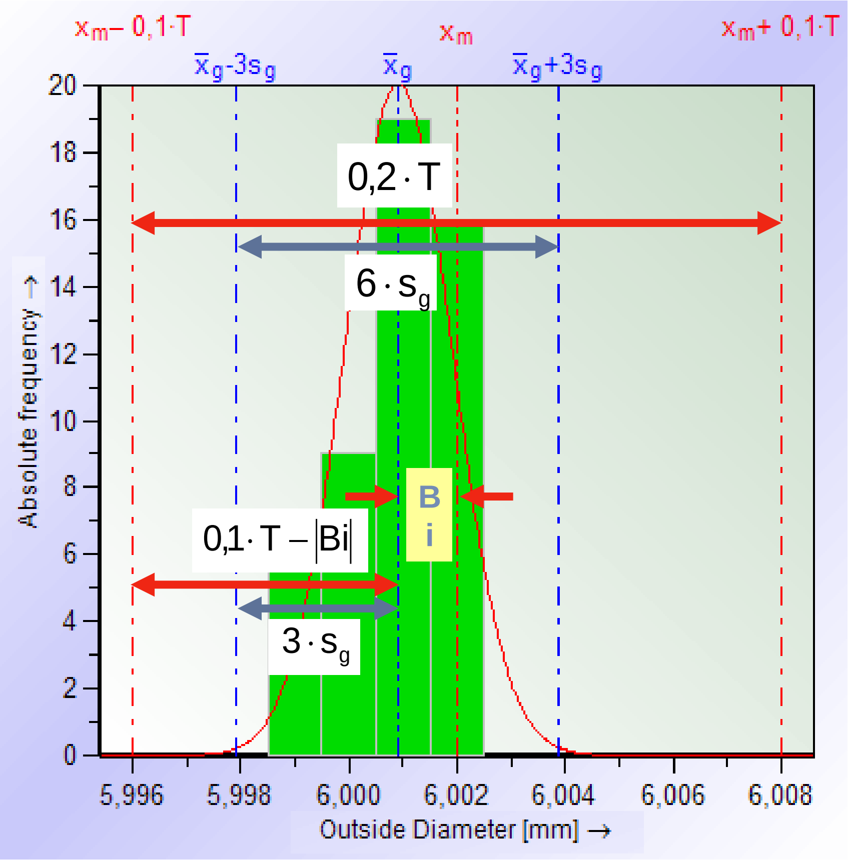


Bias $$Bi = \bar{x}_g - x_m$$

Capability indices:

$$C_g = \frac{0{,}2 \cdot T}{6 \cdot s_g}$$

$$C_{gk} = \frac{0{,}1 \cdot T - |Bi|}{3 \cdot s_g}$$

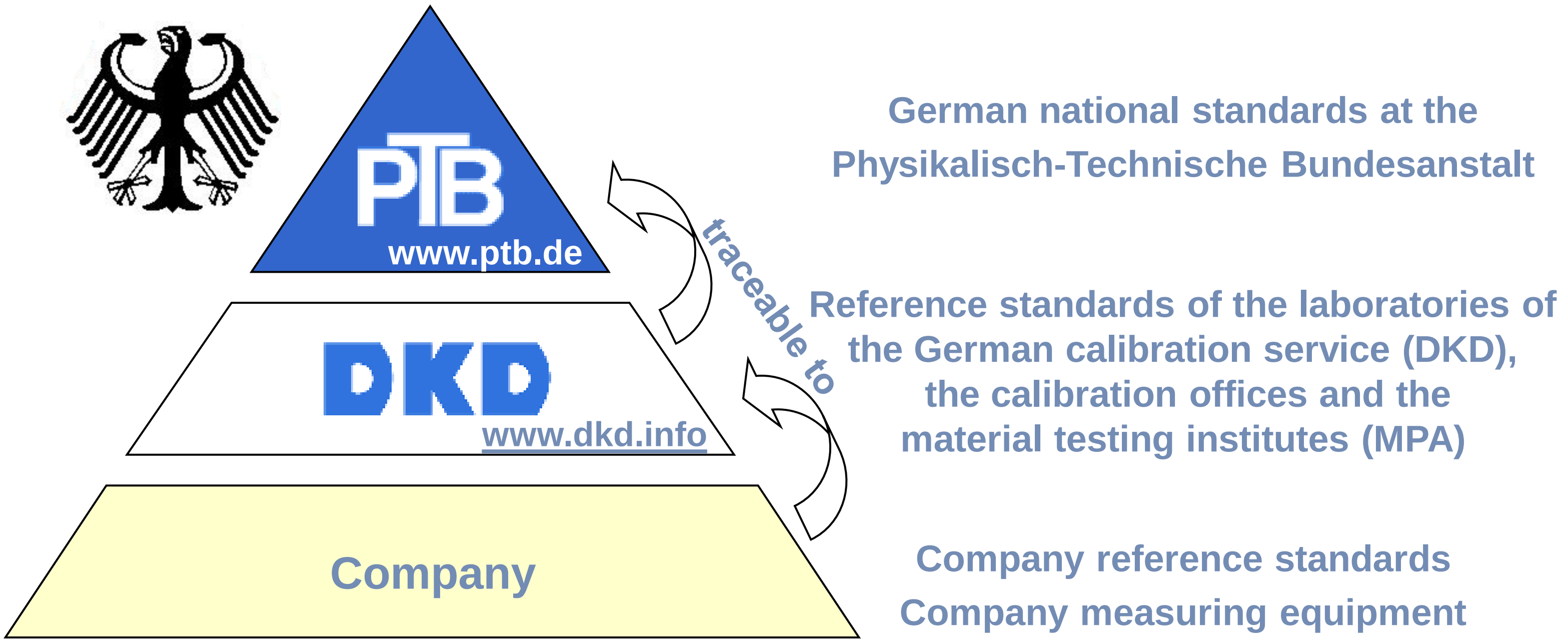


Remember:

✓ **Mean** $$\bar{x}_g = \frac{\sum x_i}{n}$$

✓ **Standard deviation** $$s_g = \sqrt{\frac{\sum(\bar{x} - x_i)^2}{n-1}}$$

- **Measurement standard**
  Realization of the definition of a given **quantity, with stated quantity value and associated measurement uncertainty**, used as a reference [VIM, 5.1]
  *Note 1: A "realization of the definition of a given quantity" can be provided by a **measuring system**, a **material measure**, or a reference material.*



Requirements for the standard

- Must enable an unambiguous result under repeatability conditions and be stable long-term
- Must have the same characteristic as the objects that the measuring equipment is later expected to measure
- Must be clearly marked as a standard, suitably calibrated, and included in the control of inspection, measurement and test equipment.
- The documented uncertainty U_{cal} of the standard should be significantly smaller than the specified tolerance T for the tested product characteristic
  - Ideal case $U_{cal} < 0.01\%T$
  - Minimum requirement $U_{cal} < 0.1\%T$
- If a corresponding object is not available, procedure 1 cannot be performed, and a suitable alternative method has to be found

Procedure 1 – Assessment with standard

Drawing Values			Collected Values			Statistics		
$x_m + 0.1 \times T$	=	6.00800	$x_{max\,g}$	=	6.002	$\bar{x}_g + 3s_g$	=	6.00388
x_m	=	6.00200	$\lvert Bi \rvert$	=	0.0011000	$\bar{x}_g$	=	6.00090
$x_m - 0.1 \times T$	=	5.99600	$x_{min\,g}$	=	5.999	$\bar{x}_g - 3s_g$	=	5.99792
$0.2 \times T$	=	0.01200	R_g	=	0.003	$6s_g$	=	0.00597
T	=	0.060	n_{tot}	=	50	s_g	=	0.00099488
Unit	=	mm						

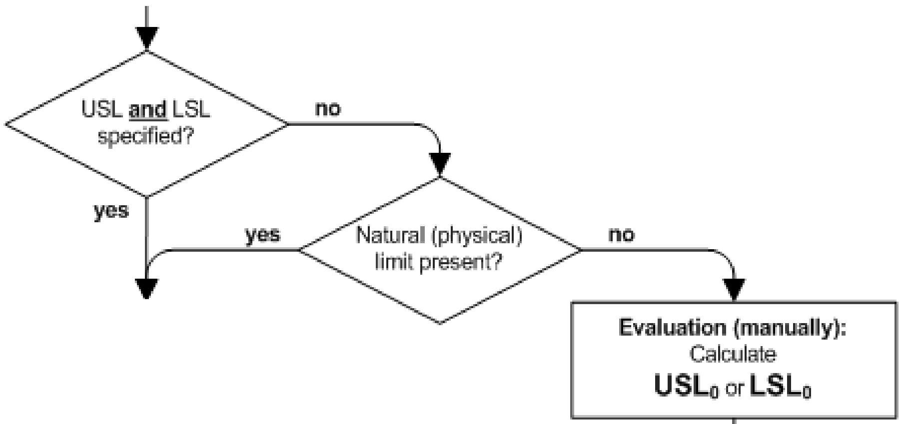
Test for Bias	Test results : significant ($\alpha \leq 0{,}1\%$)

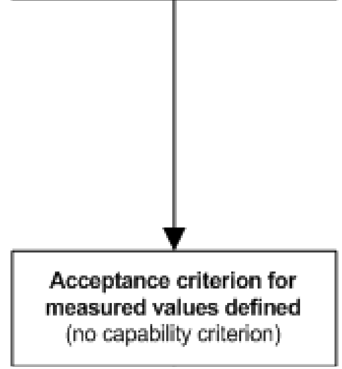
Minimum reference figure for capable measuring system

$C_g = \frac{0.2 \times T}{6 \times s_g}$	$= 1.61 \leq \mathbf{2.01} \leq 2.41$	0 … 1.33	$T_{min\,(C_g)}$	=	0.039701
$C_{gk} = \frac{0.1 \times T - \lvert \bar{x}_g - x_m \rvert}{3 \times s_g}$	$= 1.30 \leq \mathbf{1.64} \leq 1.98$	0 … 1.33	$T_{min\,(C_{gk})}$	=	0.050696
Resolution	%RES = 1.67%	0 … 5	$T_{min\,(RES)}$	=	0.020000

Measurement system capable (RES, C_g, C_{gk})

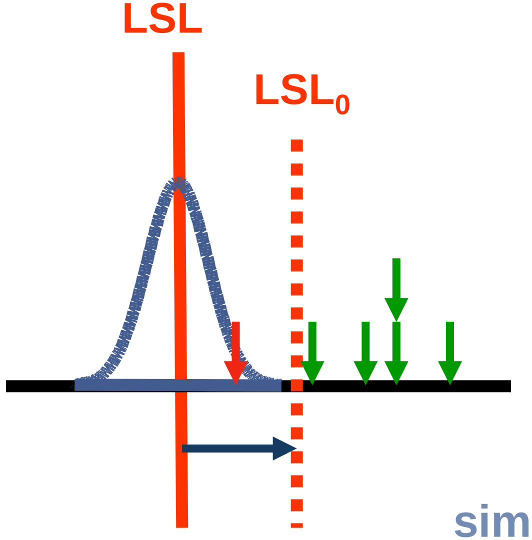
BOSCH 2005 - MSA 3 (ANOVA) - Normal: Verfahren 1

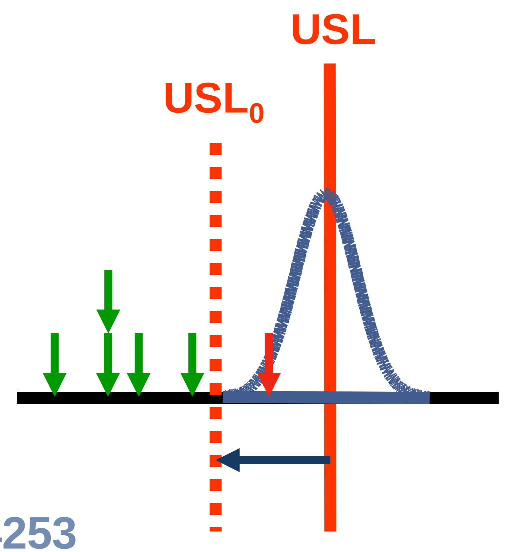




"Acceptance criterion for measured values"

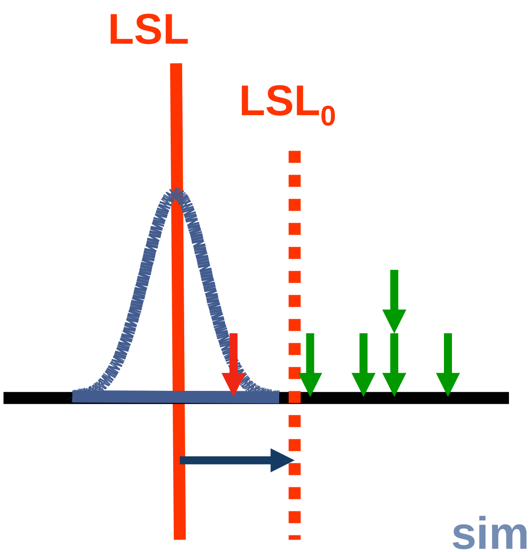
Takes into account Bias Bi and gauge variation s_g





Reduced "tolerances",
similar to approach in ISO 14253

- Imagine it this way: “The critical limit is offset by the bias plus 4 standard deviations from the specification limit”
- Standard for procedure 1 should be within ±10% of the specification limit
- Bias Bi must enter the calculation with correct sign (!)
- 4 s_g for Cg/Cgk ≥ 1.33; 5 s_g for Cg/Cgk ≥ 1.67; 6 s_g for Cg/Cgk ≥ 2.0

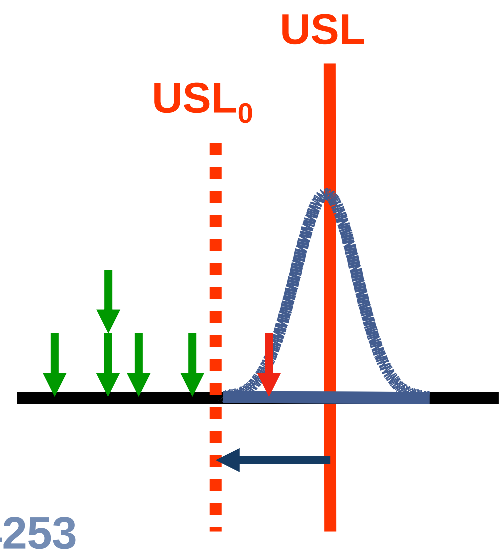


$$LSL_0 = LSL + Bi + 4s_g$$

$$USL_0 = USL + Bi - 4s_g$$

where

$$Bi = \bar{x}_g - x_m$$



Reduced “tolerances”, similar to approach in ISO 14253

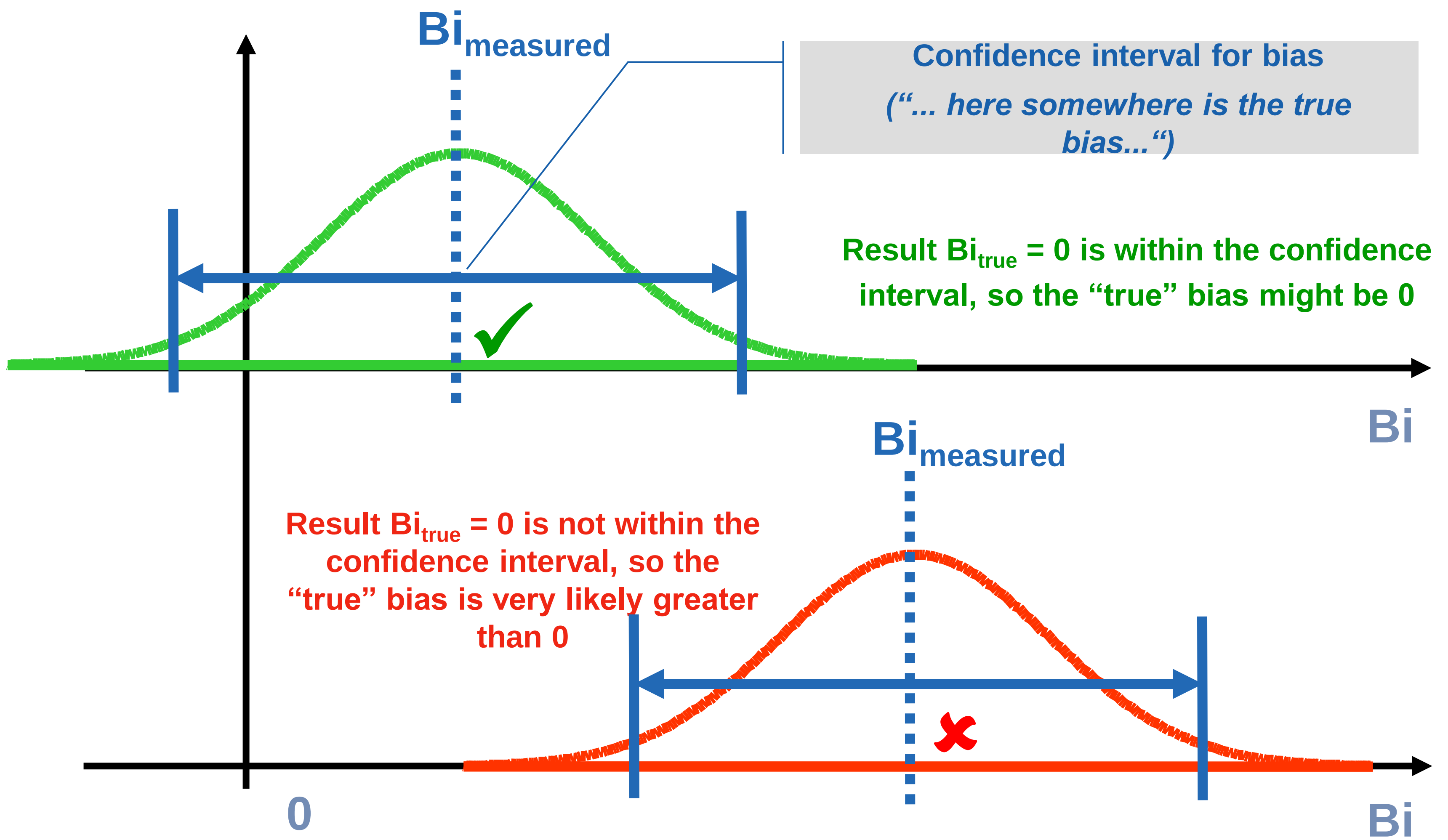
Alternative method according to AIAG MSA

- AIAG MSA does not contain the procedure 1. Instead, it recommends testing systematic measurement errors $Bi = \bar{x} - x_m$ for significance (test for significant bias)
- Approach of the test for significant bias:
  - The bias in a procedure 1 is caculated from the 25 (50) measured values
  - Any further measurement would slightly change the bias
  - In other words, the present bias value is a random variable subject to random variation (confidence interval)
  - So a bias might show even for an ideal gauge
  - If the bias is close to zero, so that zero is within the confidence interval, then the bias is negligible
  - If the bias is too large, i.e. significantly different from zero, action must be taken

Alternative method according to AIAG MSA

- Advantages of the test for significant bias
  - Statistical significance test (1-sample t-test)
  - Checks one specific component of uncertainty
- Limits/weaknesses of the test for significant bias
  - A (minimal) bias is generally unavoidable
  - A significant bias only says that there is a demonstrable bias, but does not assess it relative to a requirement (e.g. tolerance)
  - Experience has shown that it leads to problems in practice:
    - High-quality standards/measurement systems: the smaller the system variation, the more significant the bias ("… the more the systematic error stands out against the small amount of noise").
      → Criterion not satisfied, even though measurement error is very small
    - Low-quality standards/measurement systems: the converse case – the bias does not show up as significant
      → Criterion satisfied, even though error is unacceptably large
    - The more measurements are taken, the more significant the bias ("... the more the random variation averages out")

Alternative method according to AIAG MSA



Flow chart

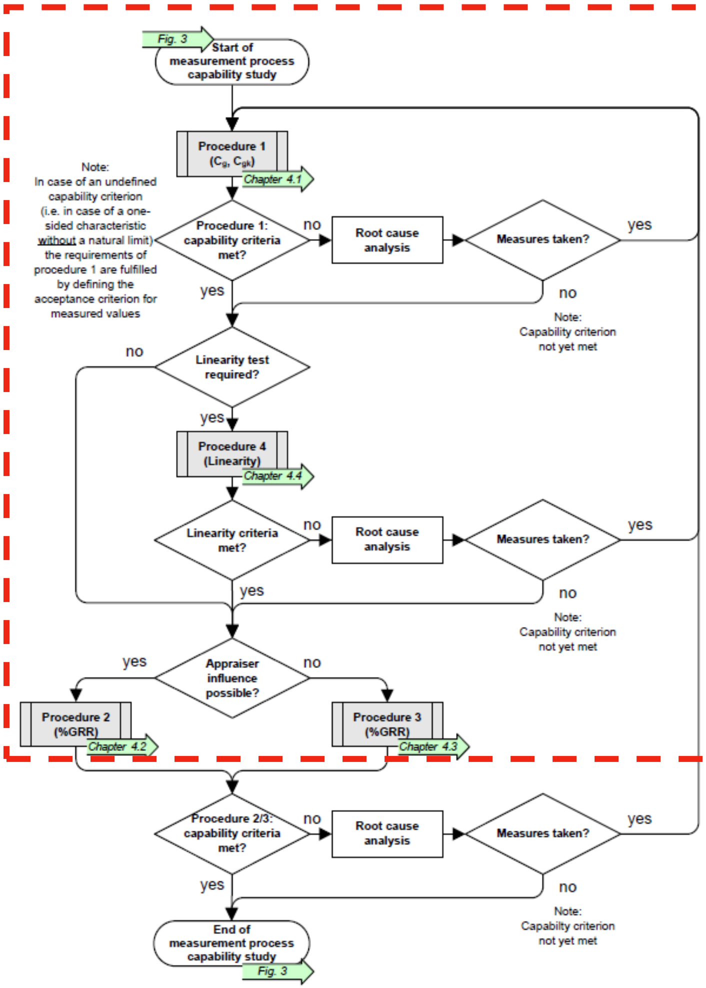


Fig. 3
Start of measurement process capability study
Procedure 1 (C_g, C_{gk})
Chapter 4.1
Note: In case of an undefined capability criterion (i.e. in case of a one-sided characteristic without a natural limit) the requirements of procedure 1 are fulfilled by defining the acceptance criterion for measured values
Procedure 1: capability criteria met?
no
yes
Root cause analysis
Measures taken?
Note: Capability criterion not yet met
Linearity test required?
Procedure 4 (Linearity)
Chapter 4.4
Linearity criteria met?
Appraiser influence possible?
Procedure 2 (%GRR)
Chapter 4.2
Procedure 3 (%GRR)
Chapter 4.3
Procedure 2/3: capability criteria met?
Note: Capabilty criterion not yet met
End of measurement process capability study
Fig. 3

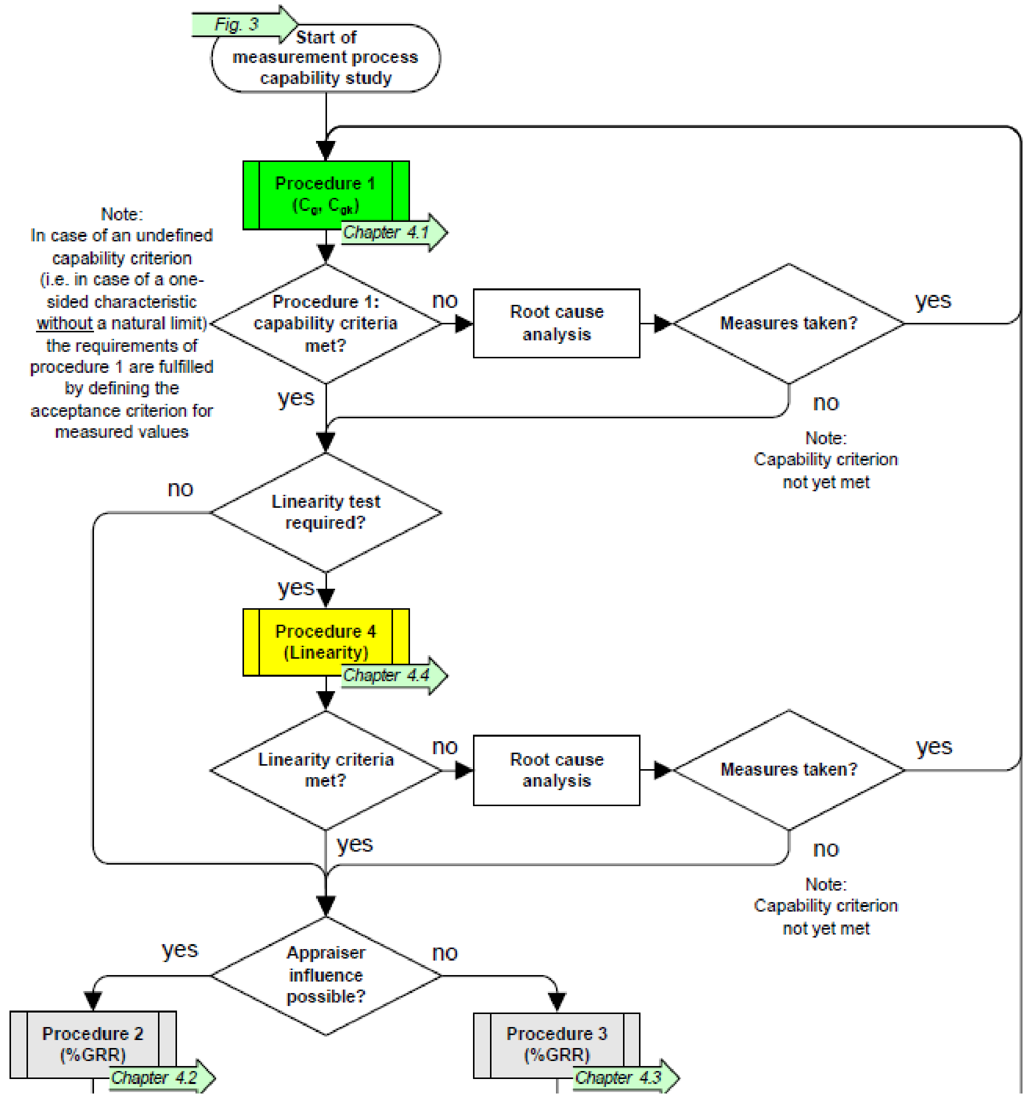


Fig. 3
Start of measurement process capability study
Procedure 1 (C_g, C_{gk})
Chapter 4.1
Note:
In case of an undefined capability criterion (i.e. in case of a one-sided characteristic without a natural limit) the requirements of procedure 1 are fulfilled by defining the acceptance criterion for measured values
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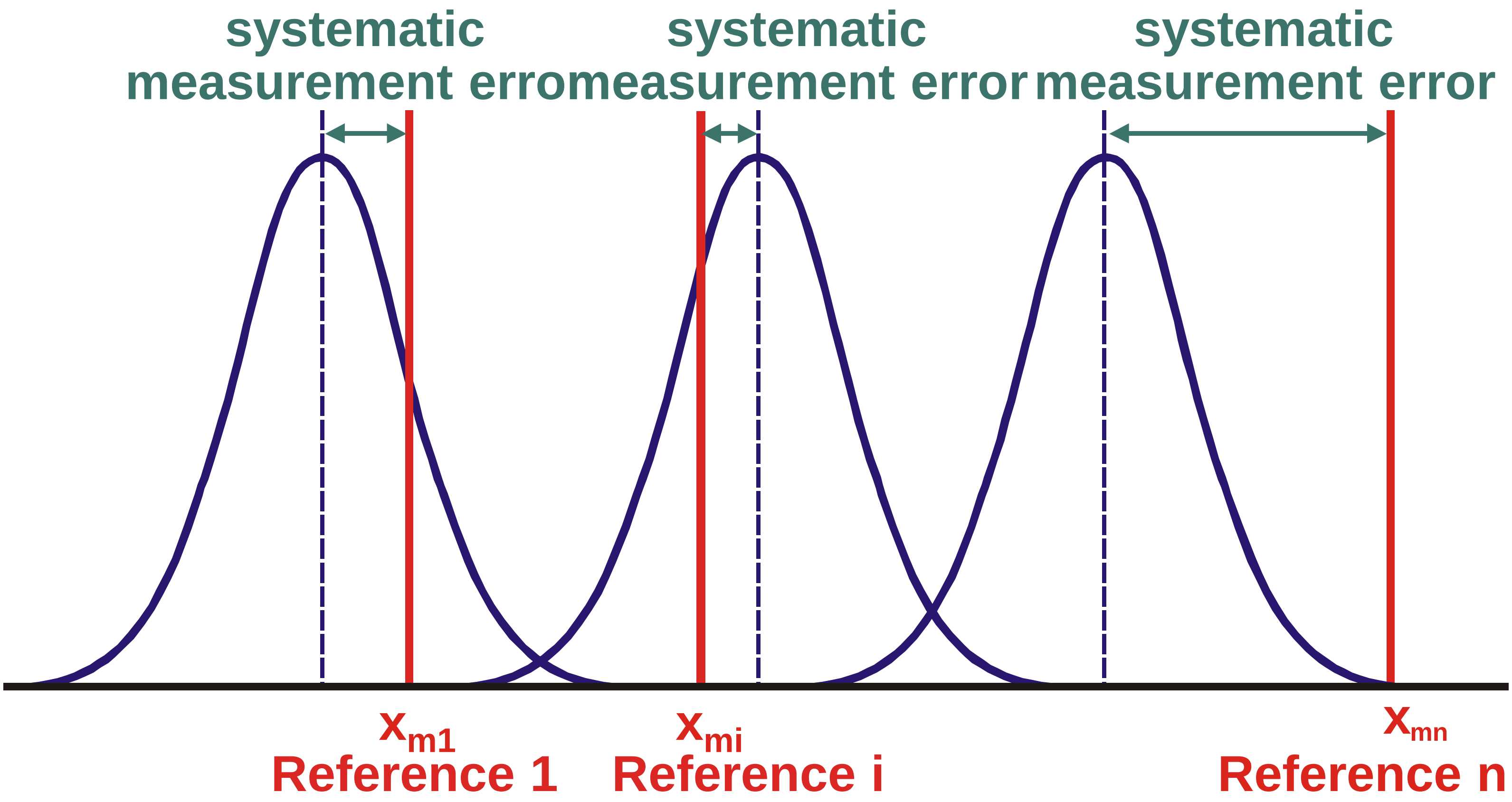
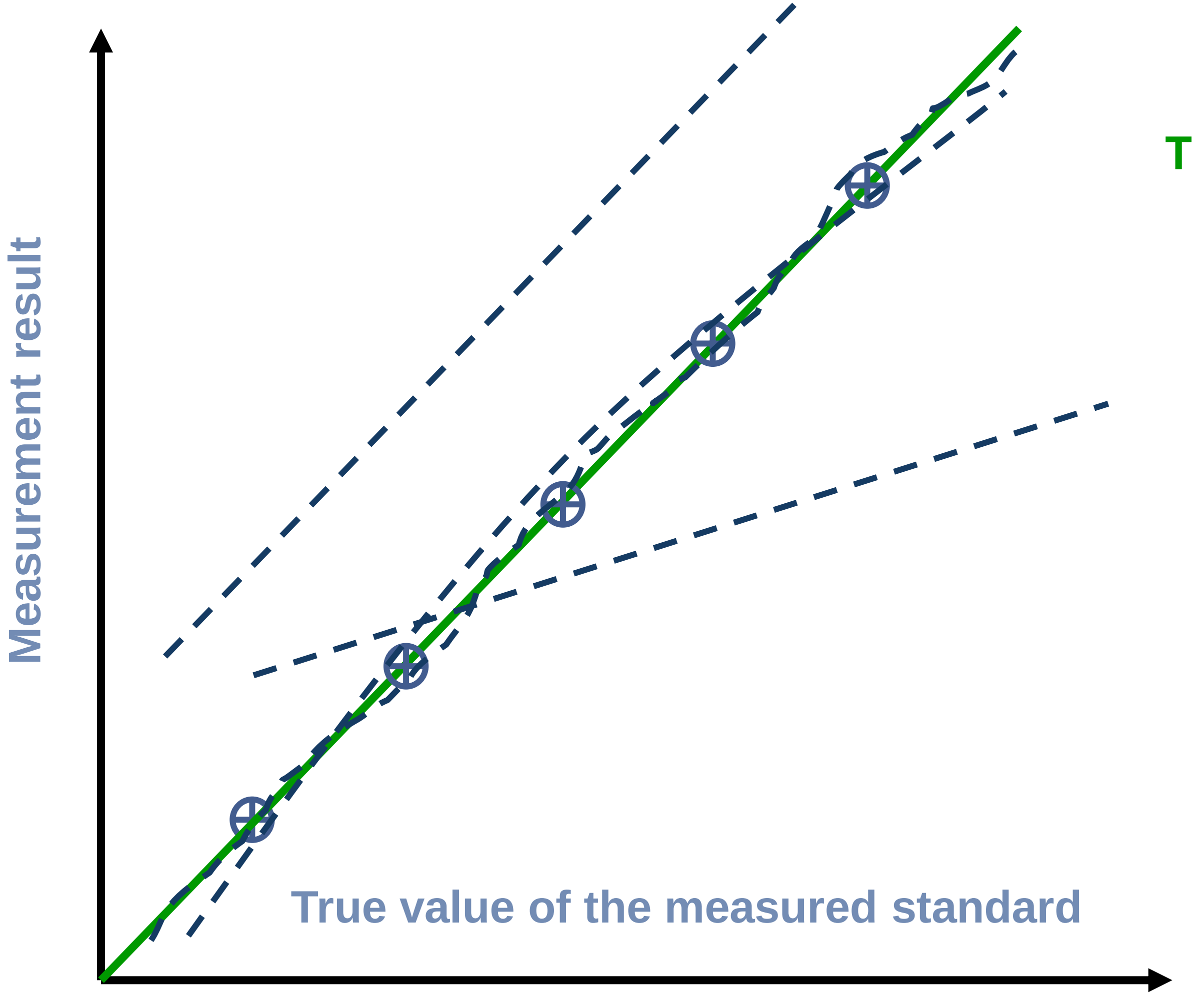
Root cause analysis
Measures taken?
yes
no
Note: Capability criterion not yet met
yes
Linearity test required?
no
yes
Procedure 4 (Linearity)
Chapter 4.4
Linearity criteria met?
no
Root cause analysis
Measures taken?
yes
no
Note: Capability criterion not yet met
yes
Appraiser influence possible?
yes
no
Procedure 2 (%GRR)
Chapter 4.2
Procedure 3 (%GRR)
Chapter 4.3


systematic
measurement erro
systematic
measurement error
systematic
measurement error
x m1
Reference 1
x mi
Reference i
x mn
Reference n

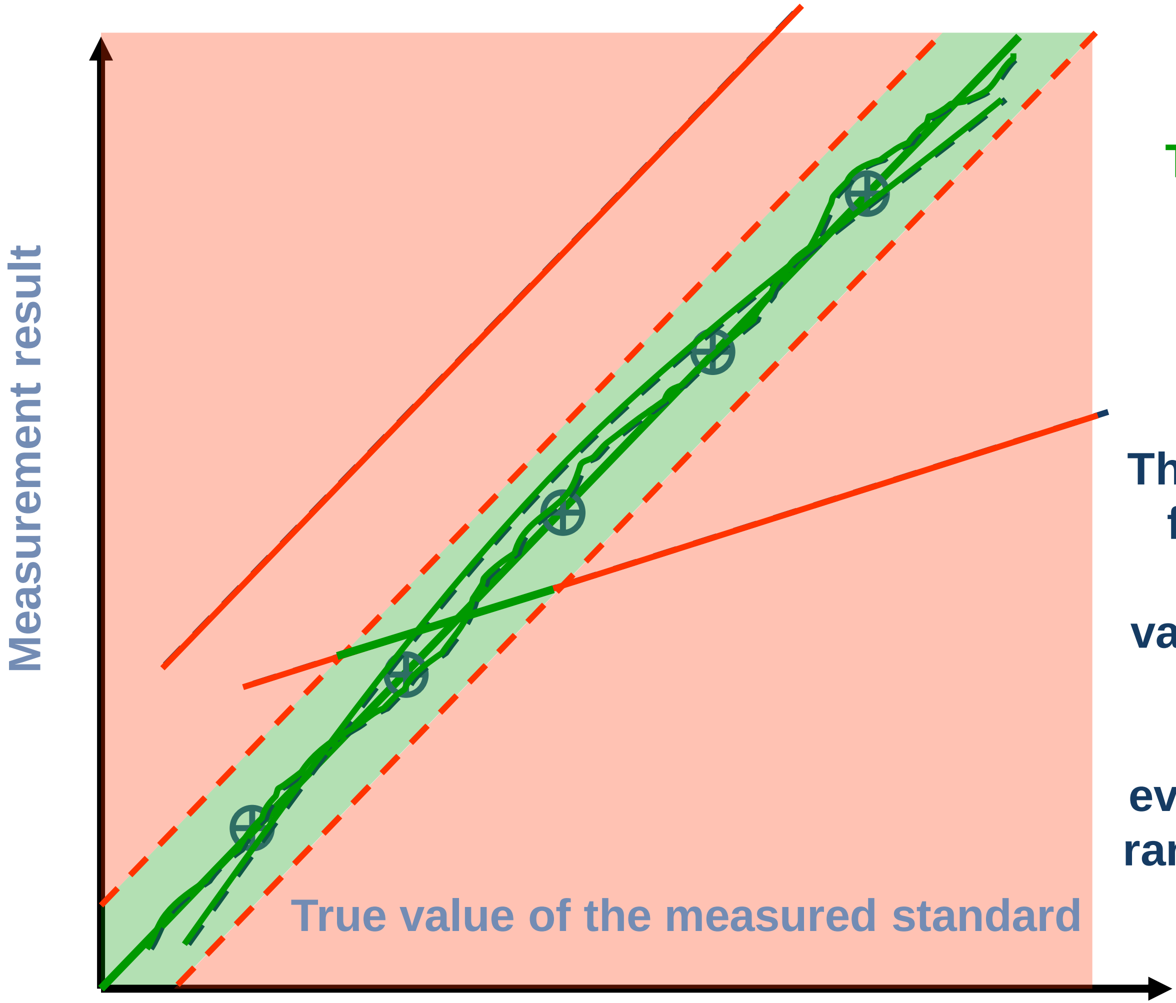
Procedure 4 – Linearity



This is "linear"!

What is not "linear"?

Procedure 4 – Linearity



This is "linear"!

This is not "linear"!

The average deviation from the reference value and the variation of measured values must be sufficiently small everywhere within the range of measurement

Procedure 4 – Linearity

- Objective
  To demonstrate that there is a sufficiently linear relationship between the values of a physical quantity to be measured and the corresponding values determined by the measuring system (systematic measurement errors are within acceptable limits across the relevant range of measurement)

- Requirements
  Often checked by the manufacturer and then as part of regular calibration of the measuring system.
  Must be demonstrated in individual cases, e.g.
  - Adjustable gain
  - Logarithmic scale
  - Error limit related to full scale

Procedure 4 – Linearity

- Conducting the study
  Unlike the other study types, a wide variety of suggested methods can be found in the literature. These are mainly:

  - Methods using explicit analysis of a mathematical linearity function (regression analysis)
    - Very complex and thus prone to errors
    - Not very intuitive and therefore difficult to evaluate in practice

  - Methods based on a "band of variation" within which the results should lie
    - No linearity study in the strict sense
    - Easy standardized implementation

Procedure 4 – Linearity

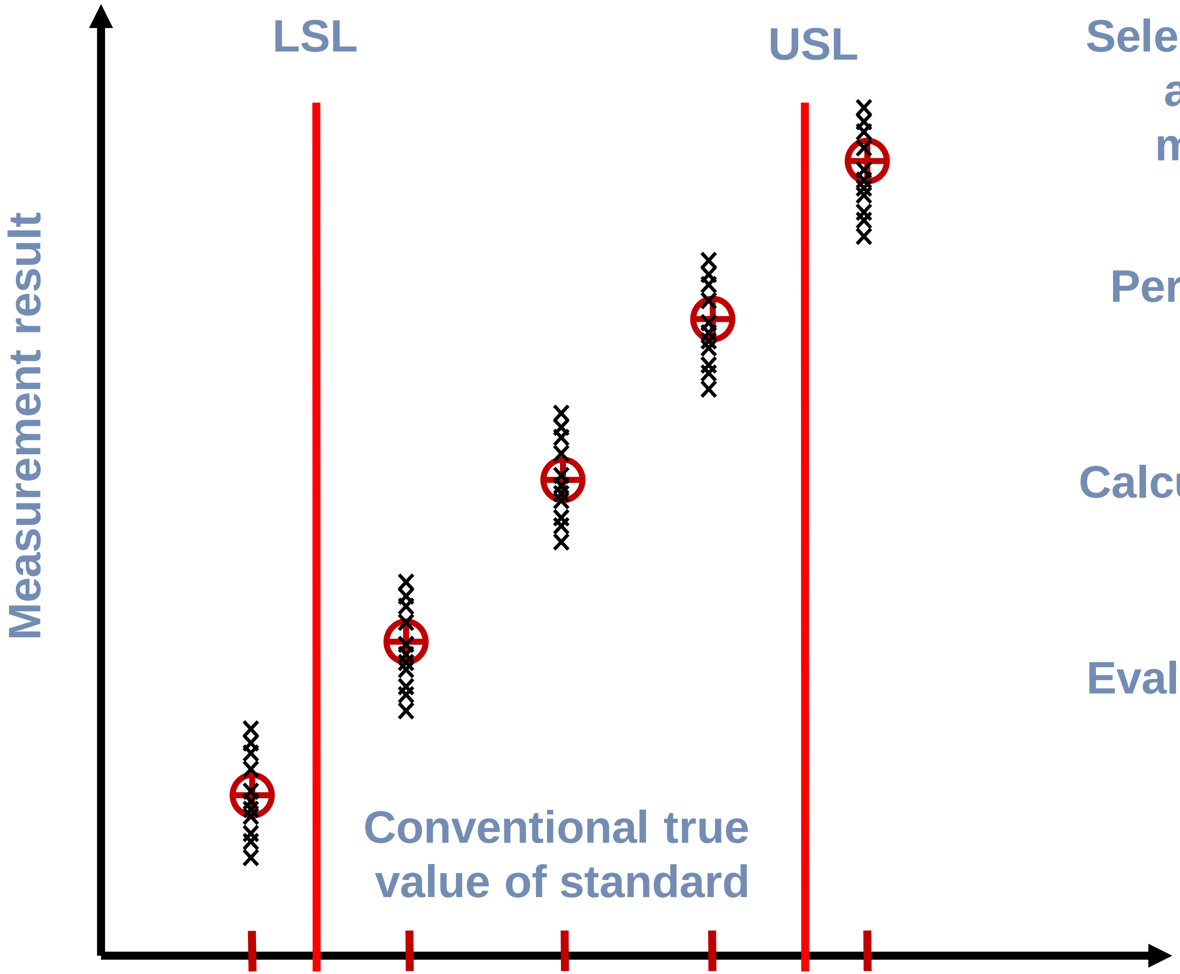
Conducting the study :

Use several standards (min. 5),

- which are distributed in a suitable manner across the relevant measuring range (e.g. equidistantly in case of a linearly scaled range).
- Perform procedure 1 for each of these standards
- Calculate the corresponding indices Cg and Cgk.

- If only 2 standards are available, it is best for these to correspond to the limits of the tolerance range

Procedure 4 – Linearity



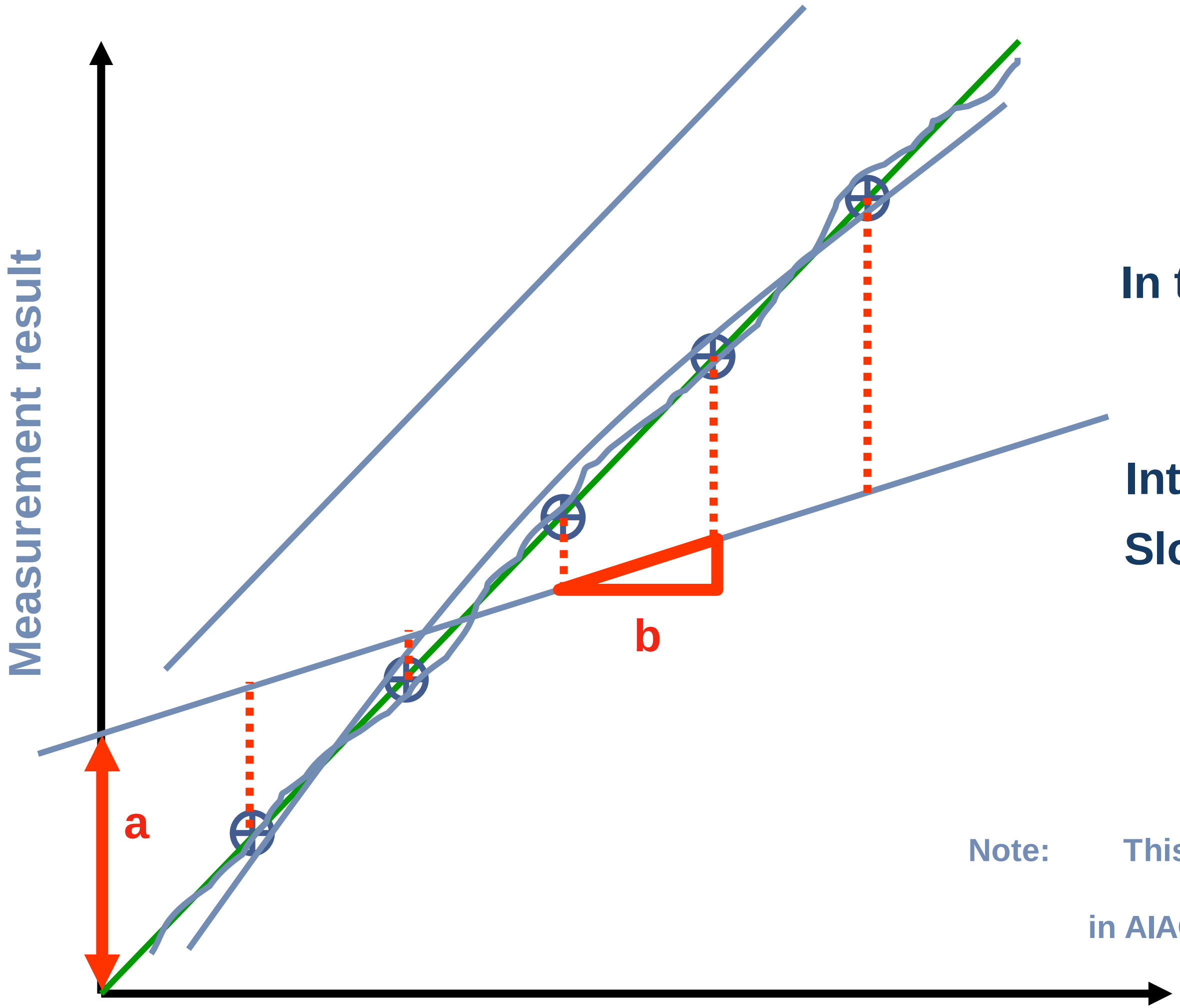
Select at least 5 standards across the relevant measurement range

Perform procedure 1 for each of them

Calculate Cg and Cgk as in procedure 1

Evaluate Cg and Cgk as in procedure 1 (Cg/Cgk ≥ 1.33)

Procedure 4 – Linearity using regression line



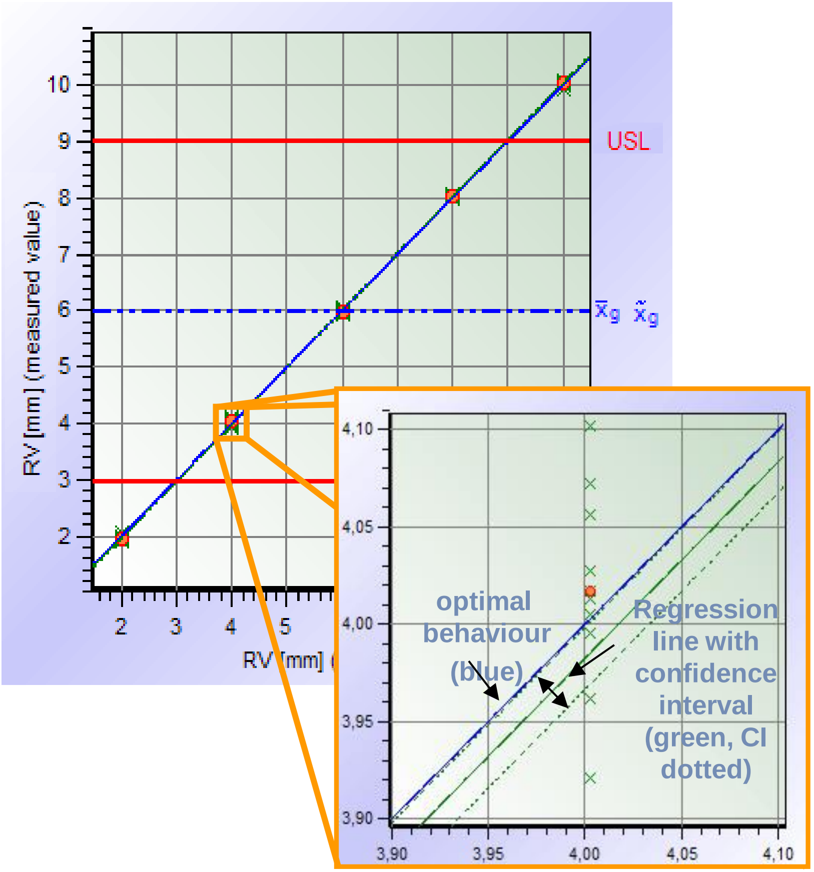
In the ideal case, the line of best fit has:

Intercept	**a = 0**
Slope	**b = 1**

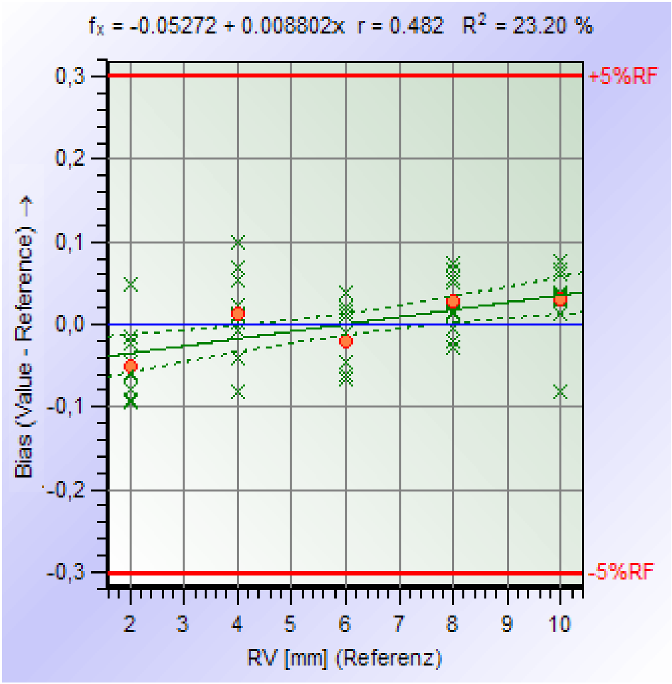
Note: This method corresponds to the method in AIAG MSA and may be a customer requirement

Procedure 4 – Linearity using regression line

Measured values



Measurement errors

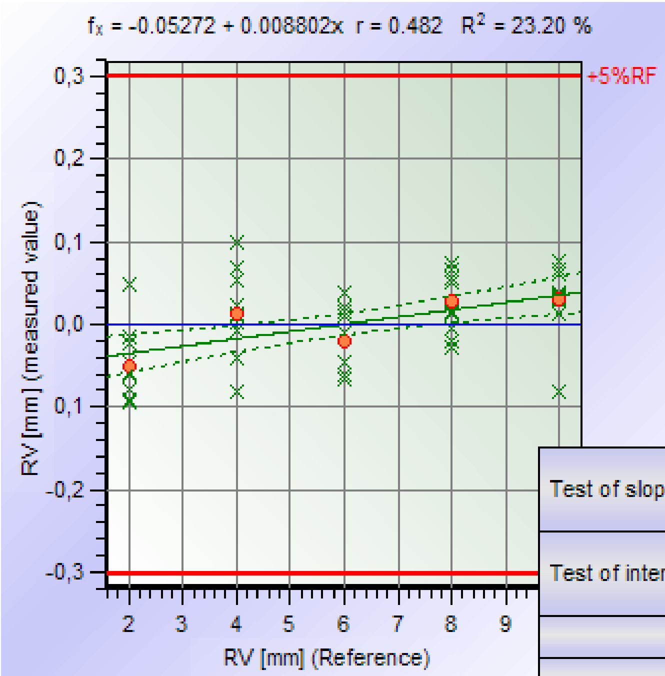


In the ideal case:

Intercept a = 0

Slope b = 0

Measurement errors



Test of slope	3.80822***
Test of intercept	3.43826**
BOSCH 2005 - MSA 3 (ARM) - Normal: Linearität	

The t-tests show:

The deviations from the ideal case are
- significant (**) for the slope b
- highly significant (***) for the intercept a

In the ideal case:

Intercept a = 0

Slope b = 0

So the measurement system is unsuitable!
Does not correspond to practice!

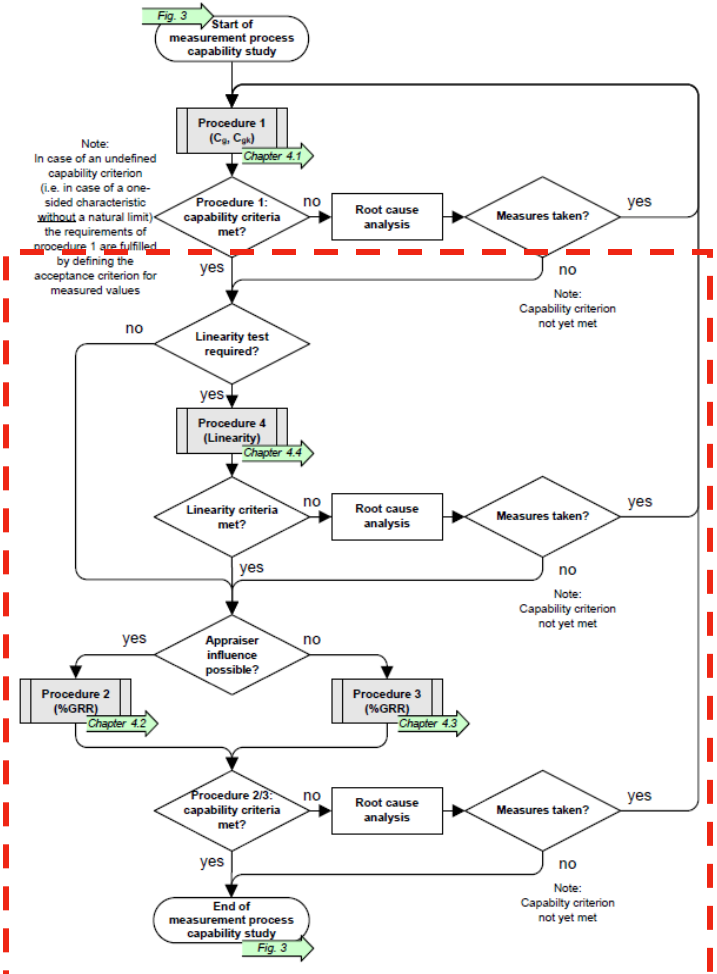
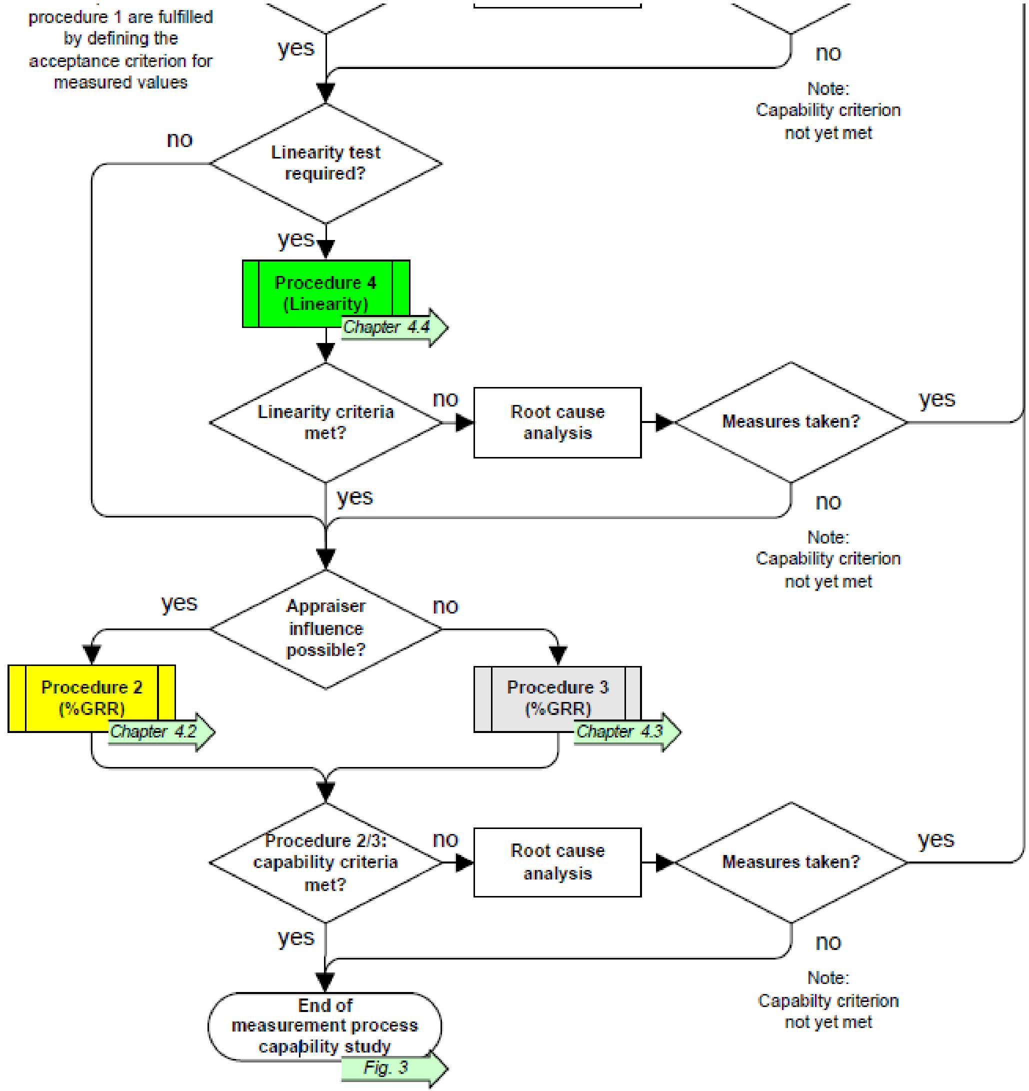


Fig. 3
Start of measurement process capability study
Procedure 1 (C_g, C_{gk})
Chapter 4.1
Note: In case of an undefined capability criterion (i.e. in case of a one-sided characteristic without a natural limit) the requirements of procedure 1 are fulfilled by defining the acceptance criterion for measured values
Procedure 1: capability criteria met?
no
Root cause analysis
Measures taken?
yes
yes
no
Note: Capability criterion not yet met
Linearity test required?
no
yes
Procedure 4 (Linearity)
Chapter 4.4
Linearity criteria met?
no
Root cause analysis
Measures taken?
yes
yes
no
Note: Capability criterion not yet met
Appraiser influence possible?
yes
no
Procedure 2 (%GRR)
Chapter 4.2
Procedure 3 (%GRR)
Chapter 4.3
Procedure 2/3: capability criteria met?
no
Root cause analysis
Measures taken?
yes
yes
no
Note: Capabilty criterion not yet met
End of measurement process capability study
Fig. 3



procedure 1 are fulfilled by defining the acceptance criterion for measured values
yes
no
Note: Capability criterion not yet met
no
Linearity test required?
yes
Procedure 4 (Linearity)
Chapter 4.4
Linearity criteria met?
no
Root cause analysis
Measures taken?
yes
yes
no
Note: Capability criterion not yet met
yes
Appraiser influence possible?
no
Procedure 2 (%GRR)
Chapter 4.2
Procedure 3 (%GRR)
Chapter 4.3
Procedure 2/3: capability criteria met?
no
Root cause analysis
Measures taken?
yes
yes
no
Note: Capabilty criterion not yet met
End of measurement process capability study
Fig. 3

Procedure 2 – Repeatability and reproducibility with appraiser influence

Objective

- To demonstrate the capability of a measurement process (as a test process for a defined characteristic) in terms of its variability, using measurements of standard production parts.

Requirements

- Appraiser influence cannot be excluded
- Production parts are available
- Parts should be within tolerance
- Measurements are repeatable

Procedure 2 – Repeatability and reproducibility with appraiser influence

Conducting the study

- Performed under operating conditions which correspond to the later operational conditions of the measuring equipment.
- Measure –
  - At least 10 series production parts that are randomly selected and repeatably measurable
  - In random sequence
  - Using at least 3 appraisers
  - Using at least 2 measurement runs
  - Under repeatability conditions and at defined measurement points.
- A new measurement series may only be begun once the previous run has been completed.

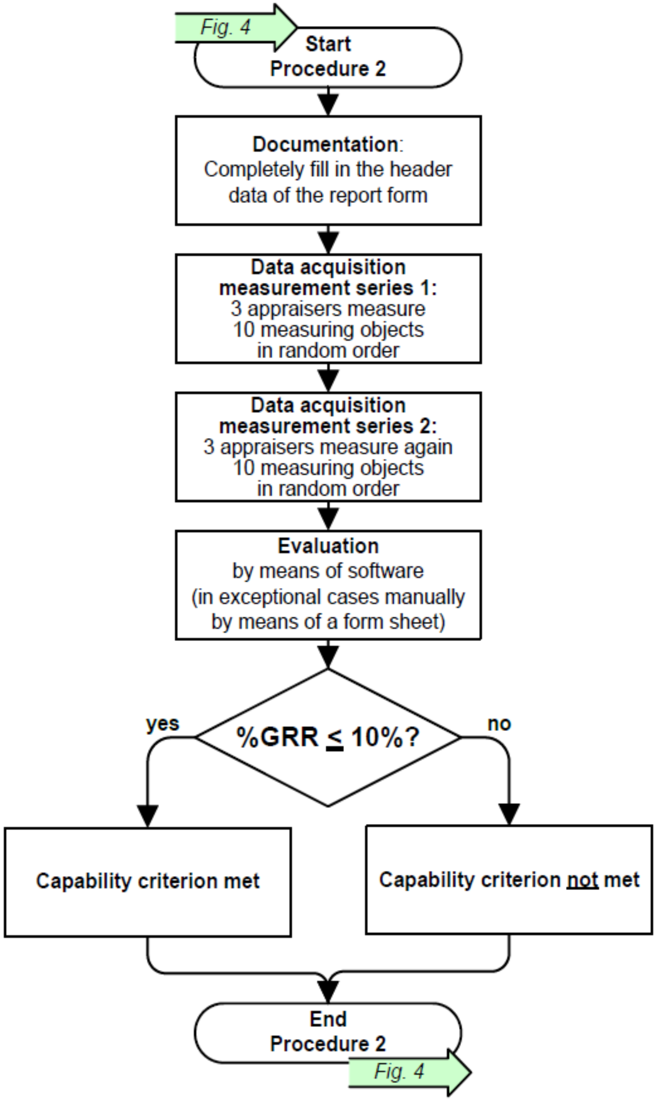
Procedure 2 – Repeatability and reproducibility with appraiser influence

- Analysis
  There are two analysis methods (models)

  - ANOVA (ANalysis Of VAriance)
    - Recommended method
    - Identifies 3 components of variation (see following slides)
    - Requires computer assistance in practice
  - ARM (Average Range Method)
    - Was the previous standard
    - “Out of date and no longer recommended”
    - Identifies only 2 components of variation
    - Can be performed manually, but uses various approximations, estimates and correction factors (historical reasons)

Procedure 2 – Process

- Documentation
- Measurement series 1
  3 appraisers measure 10 parts
  in random order
- Measurement series 2
  3 appraisers measure the 10 parts
  again in random order
- Analysis
- Capability assessment

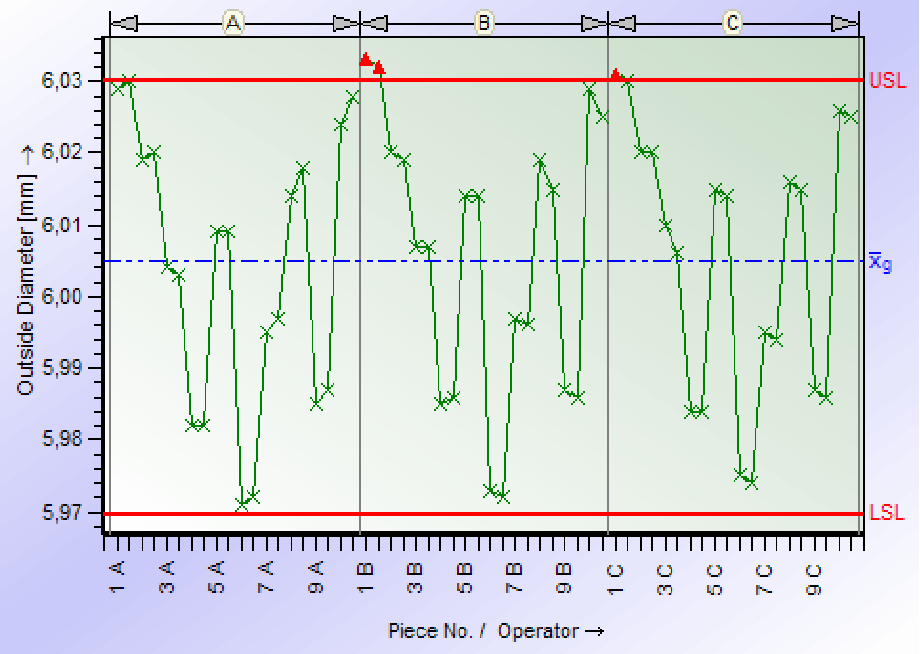


Procedure 2 – Repeatability and reproducibility with appraiser influence

➔ The measurement results will generally …

- … vary about a mean for each part (**repeatability**)
- … have different means for each appraiser (**reproducibility**)
- … have different means per part and per appraiser (**interaction**)

[*shown for two parts in the graph*]



Procedure 2 – ANOVA calculation of statistics

Part	Appraiser A 1	Appraiser A 2	Appraiser B 1	Appraiser B 2	Appraiser C 1	Appraiser C 2
1	6,029	6,030	6,033	6,032	6,031	6,030
2	6,019	6,020	6,020	6,019	6,020	6,020
3	6,004	6,003	6,007	6,007	6,010	6,006
4	5,982	5,982	5,985	5,986	5,984	5,984
5	6,009	6,009	6,014	6,014	6,015	6,014
6	5,971	5,972	5,973	5,972	5,975	5,974
7	5,995	5,997	5,997	5,996	5,995	5,994
8	6,014	6,018	6,019	6,015	6,016	6,015
9	5,985	5,987	5,987	5,986	5,987	5,986
10	6,024	6,028	6,029	6,025	6,026	6,025

➔ Total variation is composed of

- Part-to-part variation
- Variation between appraisers
- Interaction between appraiser and part
- Measuring equipment variation (“the rest”)

Procedure 2 – ANOVA calculation of statistics

Part	Appraiser A 1	Appraiser A 2	Appraiser B 1	Appraiser B 2	Appraiser C 1	Appraiser C 2	$\bar{x}$ of part, all appraisers
1	6,029	6,030	6,033	6,032	6,031	6,030	6,0308
2	6,019	6,020	6,020	6,019	6,020	6,020	6,0197
3	6,004	6,003	6,007	6,007	6,010	6,006	6,0062
4	5,982	5,982	5,985	5,986	5,984	5,984	5,9838
5	6,009	6,009	6,014	6,014	6,015	6,014	6,0125
6	5,971	5,972	5,973	5,972	5,975	5,974	5,9728
7	5,995	5,997	5,997	5,996	5,995	5,994	5,9957
8	6,014	6,018	6,019	6,015	6,016	6,015	6,0162
9	5,985	5,987	5,987	5,986	5,987	5,986	5,9863
10	6,024	6,028	6,029	6,025	6,026	6,025	6,0262

Variance of means $\bar{x}$ of all parts

s^2_{PV}= 0,000381231

➔ Total variation is composed of

- Part-to-part variation
- Variation between appraisers
- Interaction between appraiser and part
- Measuring equipment variation ("the rest")

⇨ **PV Part Variation**

Procedure 2 – ANOVA calculation of statistics

Part	Appraiser A 1	Appraiser A 2	Appraiser B 1	Appraiser B 2	Appraiser C 1	Appraiser C 2	x̄ of part all appraisers
1	6,029	6,030	6,033	6,032	6,031	6,030	6,0308
2	6,019	6,020	6,020	6,019	6,020	6,020	6,0197
3	6,004	6,003	6,007	6,007	6,010	6,006	6,0062
4	5,982	5,982	5,985	5,986	5,984	5,984	5,9838
5	6,009	6,009	6,014	6,014	6,015	6,014	6,0125
6	5,971	5,972	5,973	5,972	5,975	5,974	5,9728
7	5,995	5,997	5,997	5,996	5,995	5,994	5,9957
8	6,014	6,018	6,019	6,015	6,016	6,015	6,0162
9	5,985	5,987	5,987	5,986	5,987	5,986	5,9863
10	6,024	6,028	6,029	6,025	6,026	6,025	6,0262
x̄ of each appraiser	6,0039		6,0058		6,0054		

➔ Variance of appraisers s^2_{AV}= 9,86E-07

- Part-to-part variation
- Variation between appraisers
- Interaction between appraiser and part
- Measuring equipment variation (“the rest”)

⇨**PV Part Variation**

⇨**AV Appraiser Variation**

Procedure 2 – ANOVA calculation of statistics

Part	Appraiser A 1	Appraiser A 2	$\bar{x}$ of part at appraiser A	Appraiser B 1	Appraiser B 2	$\bar{x}$ of part at appraiser B	Appraiser C 1	Appraiser C 2	$\bar{x}$ of part at appraiser C	$\bar{x}$ of part all appraisers	Variance of means $\bar{x}$ of each part
1	6,029	6,030	6,0295	6,033	6,032	6,0325	6,031	6,030	6,0305	6,0309	$s^2_{IA1}=$ 2,33333E-06
2	6,019	6,020	6,0195	6,020	6,019	6,0195	6,020	6,020	6,0200	6,0196	$s^2_{IA2}=$ 8,33333E-08
3	6,004	6,003	6,0035	6,007	6,007	6,0070	6,010	6,006	6,0080	6,0059	$s^2_{IA3}=$ 5,58333E-06
4	5,982	5,982	5,9820	5,985	5,986	5,9855	5,984	5,984	5,9840	5,9838	$s^2_{IA4}=$ 3,08333E-06
5	6,009	6,009	6,0090	6,014	6,014	6,0140	6,015	6,014	6,0145	6,0123	$s^2_{IA5}=$ 9,25E-06
6	5,971	5,972	5,9715	5,973	5,972	5,9725	5,975	5,974	5,9745	5,9726	$s^2_{IA6}=$ 2,33333E-06
7	5,995	5,997	5,9960	5,997	5,996	5,9965	5,995	5,994	5,9945	5,9958	$s^2_{IA7}=$ 1,08333E-06
8	6,014	6,018	6,0160	6,019	6,015	6,0170	6,016	6,015	6,0155	6,0163	$s^2_{IA8}=$ 5,83333E-07
9	5,985	5,987	5,9860	5,987	5,986	5,9865	5,987	5,986	5,9865	5,9863	$s^2_{IA9}=$ 8,33333E-08
10	6,024	6,028	6,0260	6,029	6,025	6,0270	6,026	6,025	6,0255	6,0263	$s^2_{IA10}=$ 5,83333E-07
$\bar{x}$ of each appraiser	6,0039			6,0058			6,0054				Minus PV and AV $\Rightarrow s^2_{IA}$

➔ Total variation is composed of

- Part-to-part variation
- Variation between appraisers
- Interaction between appraiser and part
- Measuring equipment variation ("the rest")

⇨PV Part Variation

⇨AV Appraiser Variation

⇨IA Interaction

Procedure 2 – ANOVA calculation of statistics

Part	Appraiser A 1	Appraiser A 2	x̄ of part at appraiser A	Appraiser B 1	Appraiser B 2	x̄ of part at appraiser B	Appraiser C 1	Appraiser C 2	x̄ of part at appraiser C	x̄ of part all appraisers
1	6,029	6,030	6,0295	6,033	6,032	6,0325	6,031	6,030	6,0305	6,0309
2	6,019	6,020	6,0195	6,020	6,019	6,0195	6,020	6,020	6,0200	6,0196
3	6,004	6,003	6,0035	6,007	6,007	6,0070	6,010	6,006	6,0080	6,0059
4	5,982	5,982	5,9820	5,985	5,986	5,9855	5,984	5,984	5,9840	5,9838
5	6,009	6,009	6,0090	6,014	6,014	6,0140	6,015	6,014	6,0145	6,0123
6	5,971	5,972	5,9715	5,973	5,972	5,9725	5,975	5,974	5,9745	5,9726
7	5,995	5,997	5,9960	5,997	5,996	5,9965	5,995	5,994	5,9945	5,9958
8	6,014	6,018	6,0160	6,019	6,015	6,0170	6,016	6,015	6,0155	6,0163
9	5,985	5,987	5,9860	5,987	5,986	5,9865	5,987	5,986	5,9865	5,9863
10	6,024	6,028	6,0260	6,029	6,025	6,0270	6,026	6,025	6,0255	6,0263
x̄ of each appraiser	6,0039			6,0058			6,0054			

➔ Variance of all measurements s^2_{EV}= 0,000352 Minus variation from PV, AV and IA

- Part-to-part variation
- Variation between appraisers
- Interaction between appraiser and part
- Measuring equipment variation (“the rest”)

⇨**PV Part Variation**

⇨**AV Appraiser Variation**

⇨**IA Interaction**

⇨**EV Equipment Variation**

Procedure 2 – ANOVA calculation of statistics

Part	Appraiser A 1	Appraiser A 2	$\bar{x}$ of part at appraiser A	Appraiser B 1	Appraiser B 2	$\bar{x}$ of part at appraiser B	Appraiser C 1	Appraiser C 2	$\bar{x}$ of part at appraiser C	$\bar{x}$ of part all appraisers
1	6,029	6,030	6,0295	6,033	6,032	6,0325	6,031	6,030	6,0305	6,0309
2	6,019	6,020	6,0195	6,020	6,019	6,0195	6,020	6,020	6,0200	6,0196
3	6,004	6,003	6,0035	6,007	6,007	6,0070	6,010	6,006	6,0080	6,0059
4	5,982	5,982	5,9820	5,985	5,986	5,9855	5,984	5,984	5,9840	5,9838
5	6,009	6,009	6,0090	6,014	6,014	6,0140	6,015	6,014	6,0145	6,0123
6	5,971	5,972	5,9715	5,973	5,972	5,9725	5,975	5,974	5,9745	5,9726
7	5,995	5,997	5,9960	5,997	5,996	5,9965	5,995	5,994	5,9945	5,9958
8	6,014	6,018	6,0160	6,019	6,015	6,0170	6,016	6,015	6,0155	6,0163
9	5,985	5,987	5,9860	5,987	5,986	5,9865	5,987	5,986	5,9865	5,9863
10	6,024	6,028	6,0260	6,029	6,025	6,0270	6,026	6,025	6,0255	6,0263
$\bar{x}$ of each appraiser	6,0039			6,0058			6,0054			

➔ GRR, the variation of the measurement system, is composed of

- AV = $\hat{\sigma}_{AV}$ Appraiser Variation
- IA = $\hat{\sigma}_{IA}$ Interaction
- EV = $\hat{\sigma}_{EV}$ Equipment Variation
- ⇨ GRR = $\hat{\sigma}_{GRR}$ Gage Repeatability & Reproducibility

$$GRR = \sqrt{EV^2 + AV^2 + IA^2}$$

Procedure 2 – ANOVA calculation of statistics

	Variance	Standard dev.			
Repeatability	0.0000023556	0.0015348	0.0012799 ≤ **0.0015348** ≤ 0.0019174	%EV = 15.35%	
Reproducibility	0.00000086806	0.00093169	0.00035980 ≤ **0.00093169** ≤ 0.0062290	%AV = 9.32%	
Interaction	---			%IA = ---	
Repeatability & Reproducib	0.0000032236	0.0017954)15	0.0015827 ≤ **0.0017954** ≤ 0.0064169	%GRR = 17.95%	

Tolerance = T = 0.060			Confidence interval = 1-α = 95.000%		
Resolution	=	%RES	=	1.67%	0 5
Repeatability & Reproducibility	=	%GRR	=	17.95%	0 10 30
Part Variation	=	%PV	=	195.15%	0 50 100 150
number of distinct categories	=	ndc	=	15	0 5
Measurement system marginally capable (RES,%GRR)					
BOSCH 2005 - MSA 3 (ANOVA) - Normal: Verfahren 2					
	$T_{min\ (\%GRR)}$	0.10773	$T'_{min\ (\%GRR)}$	0.035909	

➔ GR

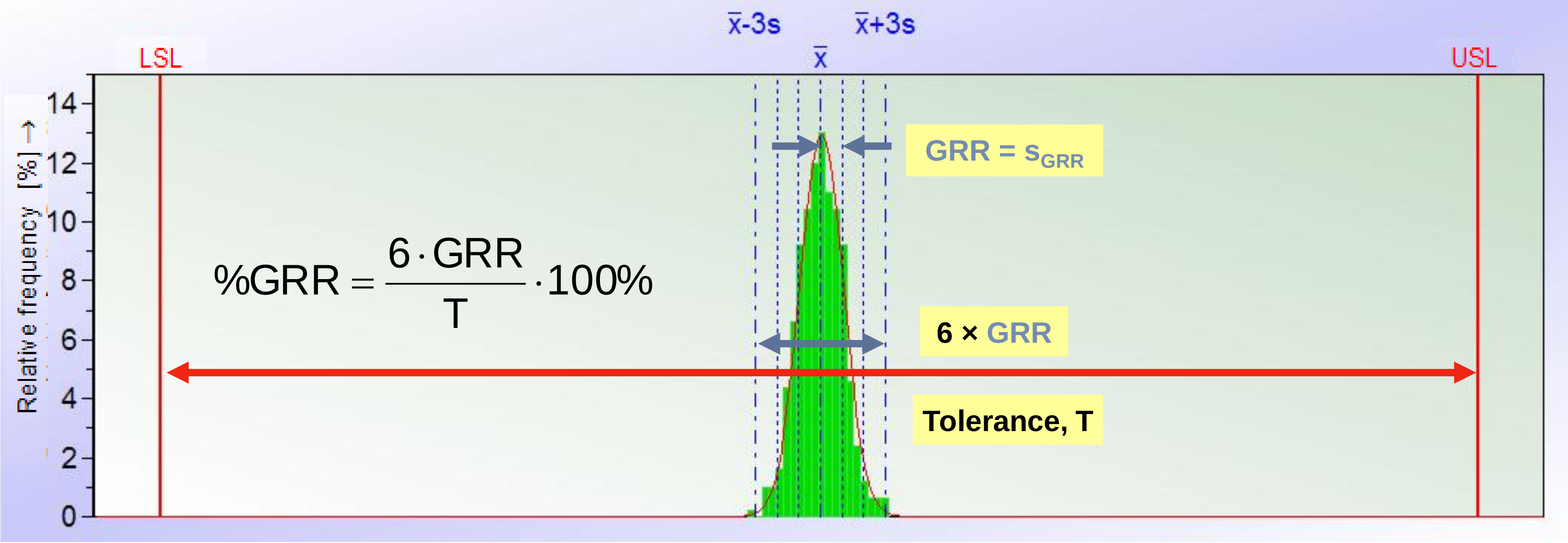
- AV = $\hat{\sigma}_{AV}$ Appraiser Variation
- IA = $\hat{\sigma}_{IA}$ Interaction
- EV = $\hat{\sigma}_{EV}$ Equipment Variation
- ⇨ GRR = $\hat{\sigma}_{GRR}$ Gage Repeatability & Reproducibility

$$GRR = \sqrt{EV^2 + AV^2 + IA^2}$$

Procedure 2 – Compare GRR to tolerance

- GRR corresponds to one standard deviation s
- Spread is typically expressed as six standard deviations (cf. procedure 1):

  Spread = 6 s = 6 × GRR
- The tolerance is used as a reference value

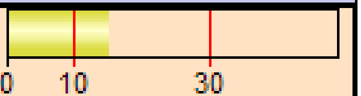


Procedure 2 – Requirements for %GRR

➔ Requirements:

- %GRR ≤ 10% capable
- 10% < %GRR ≤ 30% conditionally capable
- %GRR > 30% not capable

Repeatability & Reproducibility = $\%GRR = 6 \times \frac{GRR \times 100\%}{T}$ = 15.43%



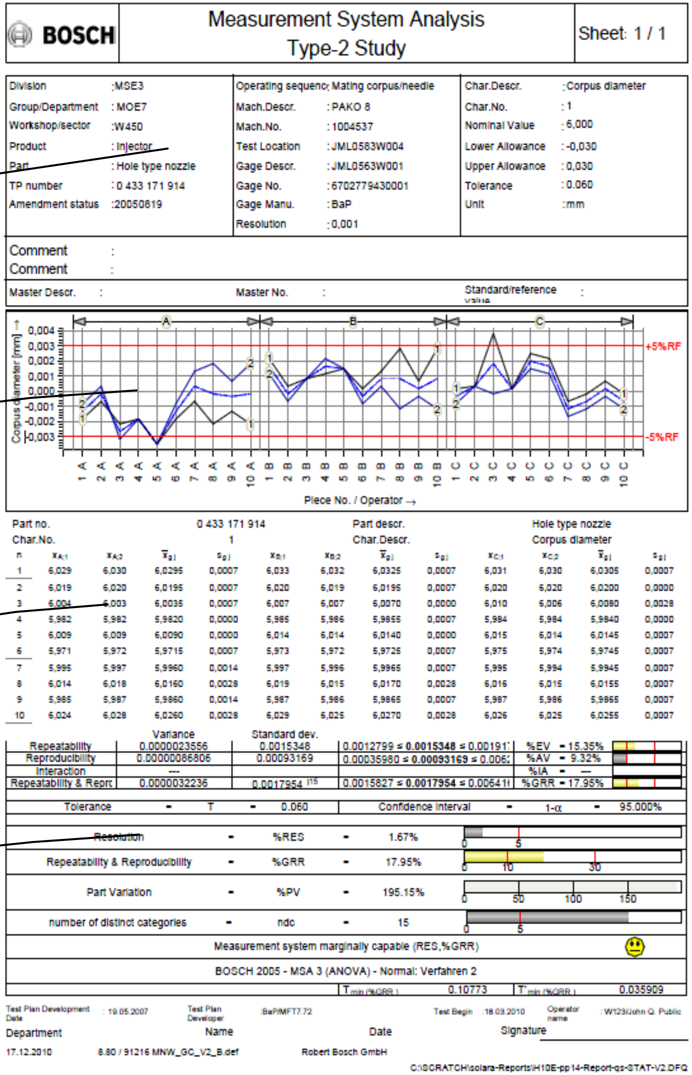
Procedure 2 – Report

Documentation

Run chart of deviations

Measurement results

Statistics and assessment



BOSCH | Measurement System Analysis Type-2 Study | Sheet: 1 / 1

Division	:MSE3	Operating sequence	Mating corpus/needle	Char.Descr.	:Corpus diameter
Group/Department	: MOE7	Mach.Descr.	: PAKO 8	Char.No.	: 1
Workshop/sector	:W450	Mach.No.	: 1004537	Nominal Value	: 6,000
Product	: Injector	Test Location	: JML0563W004	Lower Allowance	: -0,030
Part	: Hole type nozzle	Gage Descr.	: JML0563W001	Upper Allowance	: 0,030
TP number	: 0 433 171 914	Gage No.	: 6702779430001	Tolerance	: 0.060
Amendment status	:20050819	Gage Manu.	: BaP	Unit	:mm
		Resolution	: 0,001		

Comment :
Comment :

Master Descr. : Master No. : Standard/reference value :

Part no.			0 433 171 914				Part descr.			Hole type nozzle		
Char.No.			1				Char.Descr.			Corpus diameter		
n	$x_{A;1}$	$x_{A;2}$	$\bar{x}_{g\|}$	$s_{g\|}$	$x_{B;1}$	$x_{B;2}$	$\bar{x}_{g\|}$	$s_{g\|}$	$x_{C;1}$	$x_{C;2}$	$\bar{x}_{g\|}$	$s_{g\|}$
1	6,029	6,030	6,0295	0,0007	6,033	6,032	6,0325	0,0007	6,031	6,030	6,0305	0,0007
2	6,019	6,020	6,0195	0,0007	6,020	6,019	6,0195	0,0007	6,020	6,020	6,0200	0,0000
3	6,004	6,003	6,0035	0,0007	6,007	6,007	6,0070	0,0000	6,010	6,006	6,0080	0,0028
4	5,982	5,982	5,9820	0,0000	5,985	5,986	5,9855	0,0007	5,984	5,984	5,9840	0,0000
5	6,009	6,009	6,0090	0,0000	6,014	6,014	6,0140	0,0000	6,015	6,014	6,0145	0,0007
6	5,971	5,972	5,9715	0,0007	5,973	5,972	5,9725	0,0007	5,975	5,974	5,9745	0,0007
7	5,995	5,997	5,9960	0,0014	5,997	5,996	5,9965	0,0007	5,995	5,994	5,9945	0,0007
8	6,014	6,018	6,0160	0,0028	6,019	6,015	6,0170	0,0028	6,016	6,015	6,0155	0,0007
9	5,985	5,987	5,9860	0,0014	5,987	5,986	5,9865	0,0007	5,987	5,986	5,9865	0,0007
10	6,024	6,028	6,0260	0,0028	6,029	6,025	6,0270	0,0028	6,026	6,025	6,0255	0,0007

	Variance	Standard dev.		
Repeatability	0.0000023556	0.0015348	0.0012799 ≤ **0.0015348** ≤ 0.00191	%EV = 15.35%
Reproducibility	0.00000086806	0.00093169	0.00035980 ≤ **0.00093169** ≤ 0.006	%AV = 9.32%
Interaction	---			%IA = ---
Repeatability & Repro	0.0000032236	0.0017954 [15]	0.0015827 ≤ **0.0017954** ≤ 0.00641	%GRR = 17.95%

Tolerance	=	T	=	0.060	Confidence interval	= 1-α =	95.000%
Resolution	=	%RES	=	1.67%			
Repeatability & Reproducibility	=	%GRR	=	17.95%			
Part Variation	=	%PV	=	195.15%			
number of distinct categories	=	ndc	=	15			

Measurement system marginally capable (RES,%GRR)

BOSCH 2005 - MSA 3 (ANOVA) - Normal: Verfahren 2

$T_{min\,(\%GRR)}$ 0.10773 | $T'_{min\,(\%GRR)}$ 0.035909

Test Plan Development Date : 19.05.2007 Test Plan Developer :BaP/MFT7.72 Test Begin :18.03.2010 Operator name : W123/John Q. Public

Department Name Date Signature

17.12.2010 8.80 / 91216 MNW_GC_V2_B.def Robert Bosch GmbH

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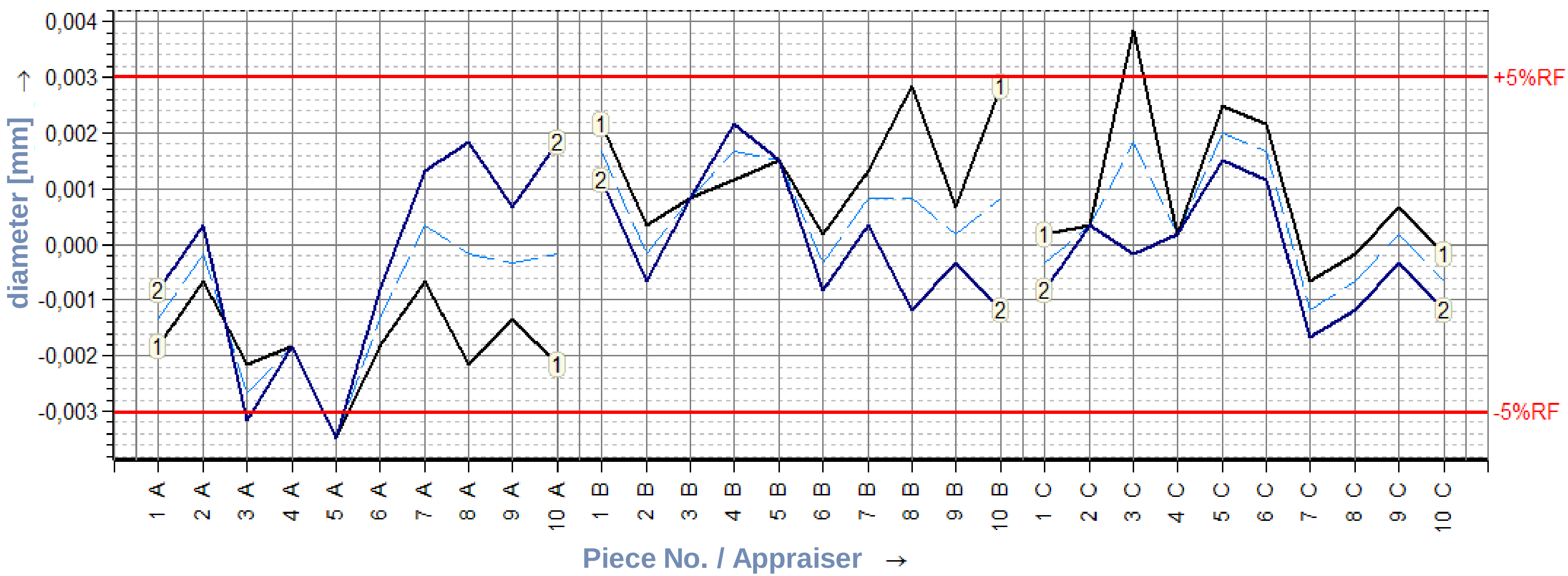
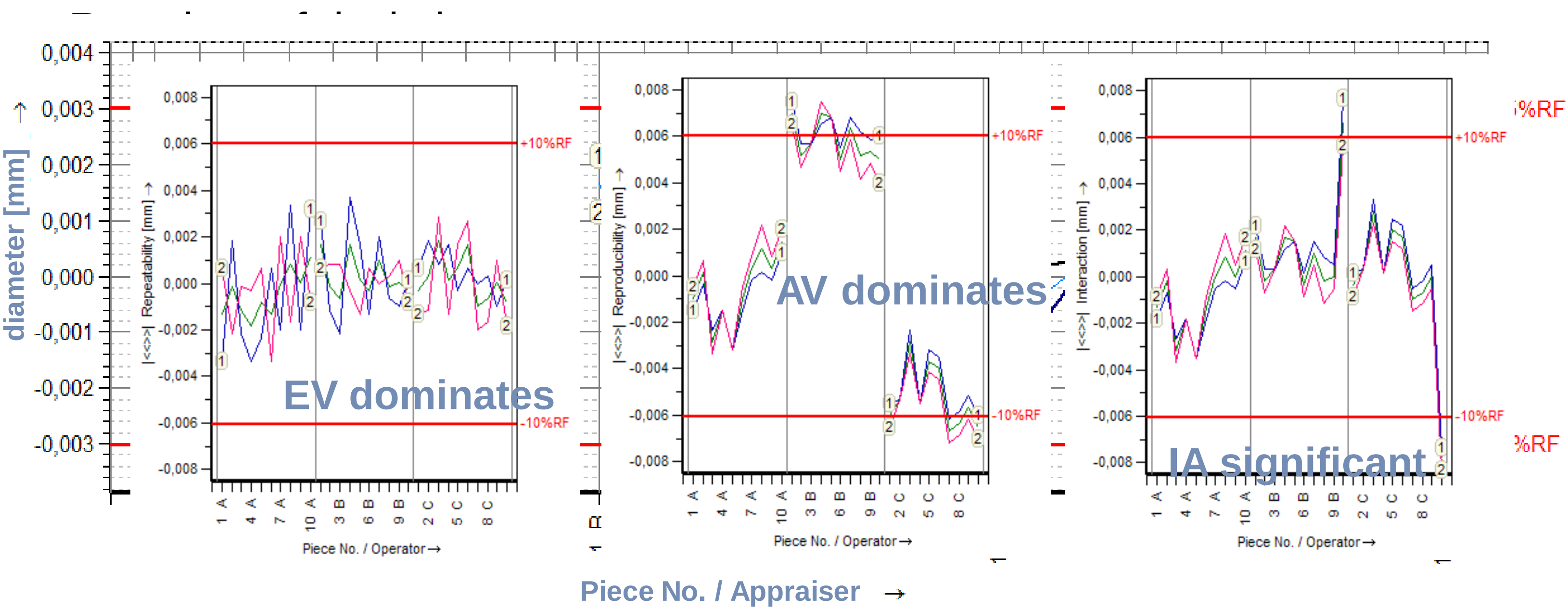
➔ Run chart of deviations



- Deviation of individual measurement from the mean of all measurements for the relevant part
- Graphical representation of the variation statistics EV, AV und IA



- Deviation of individual measurement from the mean of all measurements for the relevant part
- Graphical representation of the variation statistics EV, AV und IA

Procedure 2 – Report

➔ Statistics

	Variance	Standard dev.			
Repeatability	0.0000023556	0.0015348	0.0012799 ≤ **0.0015348** ≤ 0.0019174	%EV = 15.35%	
Reproducibility	0.00000086806	0.00093169	0.00035980 ≤ **0.00093169** ≤ 0.0062290	%AV = 9.32%	
Interaction	---			%IA = ---	
Repeatability & Reproducib	0.0000032236	0.0017954)15	0.0015827 ≤ **0.0017954** ≤ 0.0064169	%GRR = 17.95%	

Tolerance	=	T	=	0.060	Confidence interval	=	1-α	=	95.000%

Resolution	=	%RES	=	1.67%	0 5
Repeatability & Reproducibility	=	%GRR	=	17.95%	0 10 30
Part Variation	=	%PV	=	195.15%	0 50 100 150
number of distinct categories	=	ndc	=	15	0 5

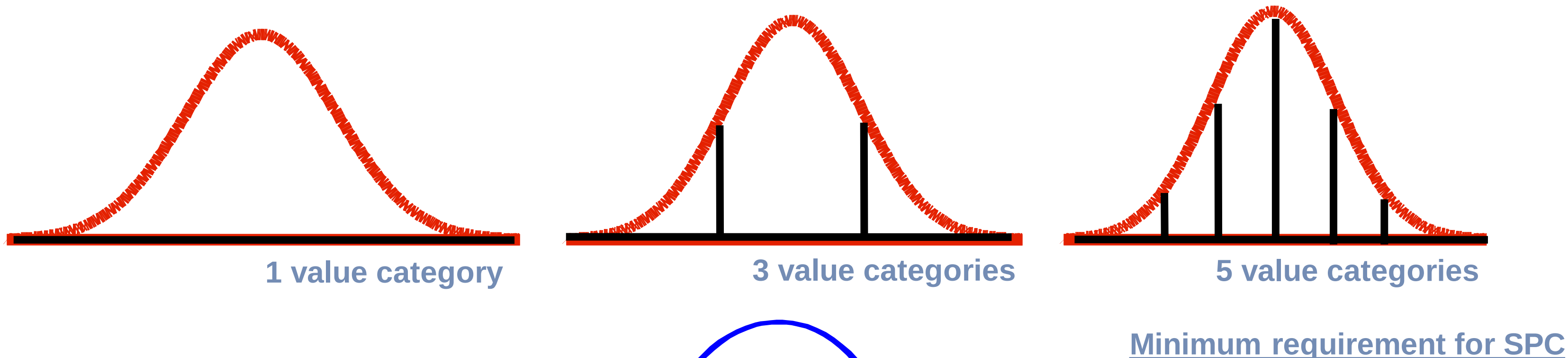
Measurement system marginally capable (RES,%GRR)

Bosch Heft 10 (2003)/MSA 3 (ANOVA) - Normal: Verfahren 2

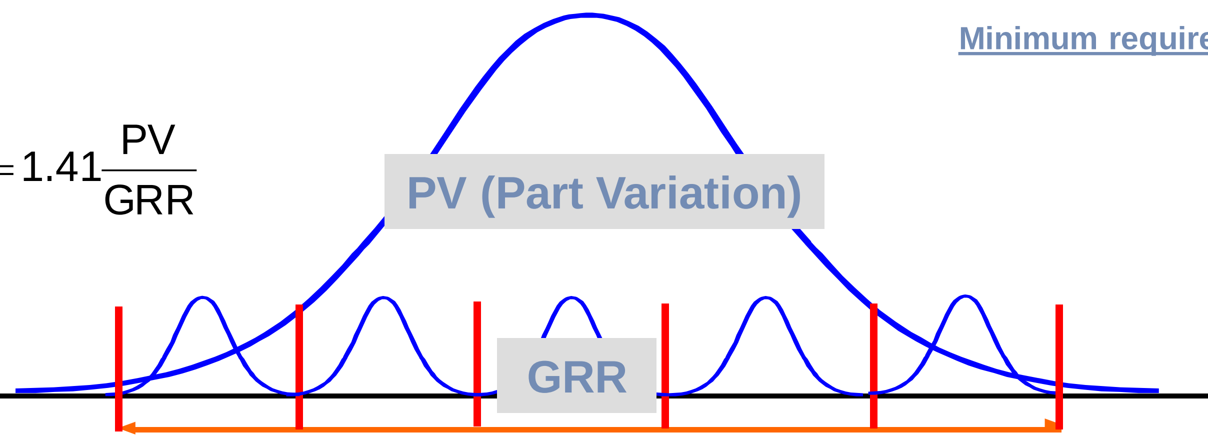
$T_{min\ (\%GRR)}$	0.10773	$T'_{min\ (\%GRR)}$	0.035909

Procedure 2 – Number of Distinct Categories ndc

➔ Requirement: ndc ≥ 5



$$ndc = 1.41\frac{PV}{GRR}$$



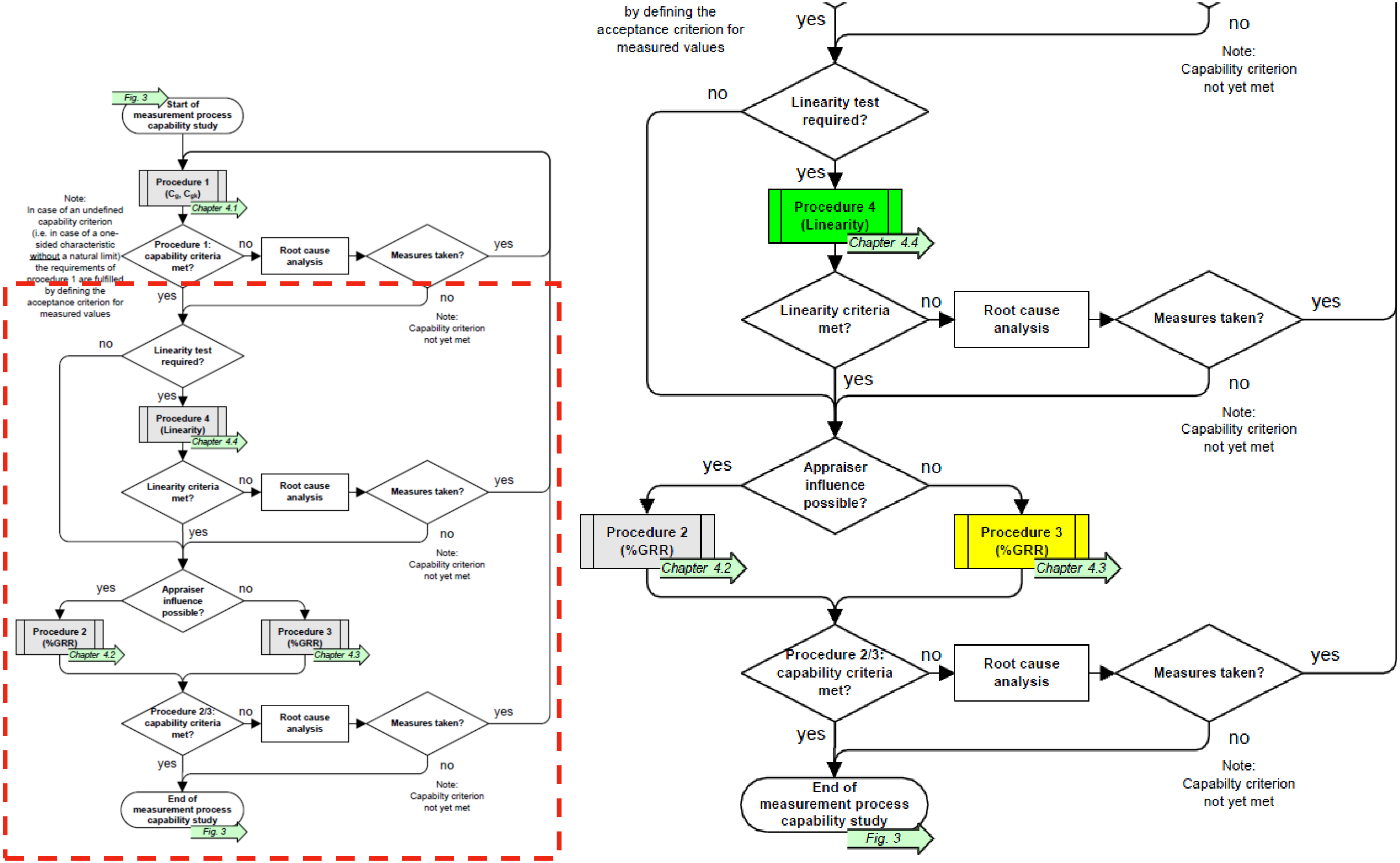


Fig. 3
Start of measurement process capability study
Procedure 1 (C_g, C_{gk})
Chapter 4.1
Note: In case of an undefined capability criterion (i.e. in case of a one-sided characteristic without a natural limit) the requirements of procedure 1 are fulfilled by defining the acceptance criterion for measured values
Procedure 1: capability criteria met?
no
Root cause analysis
Measures taken?
yes
no
Note: Capability criterion not yet met
yes
Linearity test required?
no
yes
Procedure 4 (Linearity)
Chapter 4.4
Linearity criteria met?
no
Root cause analysis
Measures taken?
yes
no
Note: Capability criterion not yet met
yes
Appraiser influence possible?
yes
no
Procedure 2 (%GRR)
Chapter 4.2
Procedure 3 (%GRR)
Chapter 4.3
Procedure 2/3: capability criteria met?
no
Root cause analysis
Measures taken?
yes
no
Note: Capabilty criterion not yet met
yes
End of measurement process capability study
Fig. 3

Procedure 3 – Repeatability and reproducibility without appraiser influence

- Objective
  To demonstrate the capability of a measurement process (as a test process for a defined characteristic) in terms of its variability, using measurements of production parts, without appraiser influence.

- Requirements
  Before conducting procedure 3, a careful check has to be performed to verify that appraiser influence on measured values can be excluded.
  This being a special case of procedure 2, the same requirements apply.

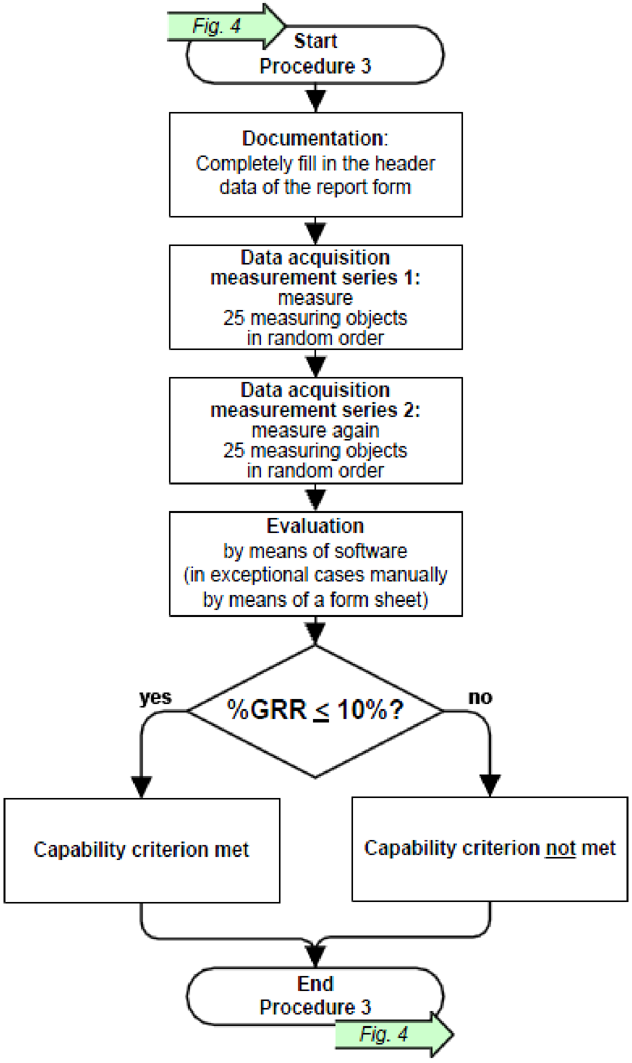
Procedure 3 – Repeatability and reproducibility without appraiser influence

- Conducting the study
  Performed under operating conditions which correspond to the later operational conditions of the measuring equipment.
  Measure –
  - At least 25 series production parts that are randomly selected and repeatably measurable
  - In random sequence
  - Using at least 2 measurement series
  - Under repeatability conditions and at defined measurement points.

- Analysis
  - Per procedure 2 using ANOVA
  - ARM analysis "out of date and no longer recommended"

Procedure 3 – Process

- ➔ Documentation
- ➔ Measurement series 1
  Measure 25 parts in random order
- ➔ Measurement series 2
- ➔ Measure the 25 parts again in random order
- ➔ Analysis
- ➔ Capability assessment



Procedure 3 – ANOVA calculation of statistics

	Appraiser A			Appraiser B			Appraiser C			
n	$x_{A;1}$	$x_{A;2}$	$\bar{x}_{g\,j}$	$x_{B;1}$	$x_{B;2}$	$\bar{x}_{g\,j}$	$x_{C;1}$	$x_{C;2}$	$\bar{x}_{g\,j}$	$\bar{x}_{g\,n}$
1	6,029	6,030	6,0295	6,033	6,032	6,0325	6,031	6,030	6,0305	6,03083
2	6,019	6,020	6,0195	6,020	6,019	6,0195	6,020	6,020	6,0200	6,01967
3	6,004	6,003	6,0035	6,007	6,007	6,0070	6,010	6,006	6,0080	6,00617
4	5,982	5,982	5,9820	5,985	5,986	5,9855	5,984	5,984	5,9840	5,98383
5	6,009	6,009	6,0090	6,014	6,014	6,0140	6,015	6,014	6,0145	6,01250
6	5,971	5,972	5,9715	5,973	5,972	5,9725	5,975	5,974	5,9745	5,97283
7	5,995	5,997	5,9960	5,997	5,996	5,9965	5,995	5,994	5,9945	5,99567
8	6,014	6,018	6,0160	6,019	6,015	6,0170	6,016	6,015	6,0155	6,01617
9	5,985	5,987	5,9860	5,987	5,986	5,9865	5,987	5,986	5,9865	5,98633
10	6,024	6,028	6,0260	6,029	6,025	6,0270	6,026	6,025	6,0255	6,02617

→ Total variation is composed of

25

- Part-to-part variation
- Variation between appraisers
- Interaction between appraiser and part
- Measuring equipment variation ("the rest")

⇨PV Part Variation

⇨AV Appraiser Variation

⇨IA Interaction

⇨EV Equipment Variation

Procedure 3 – Report

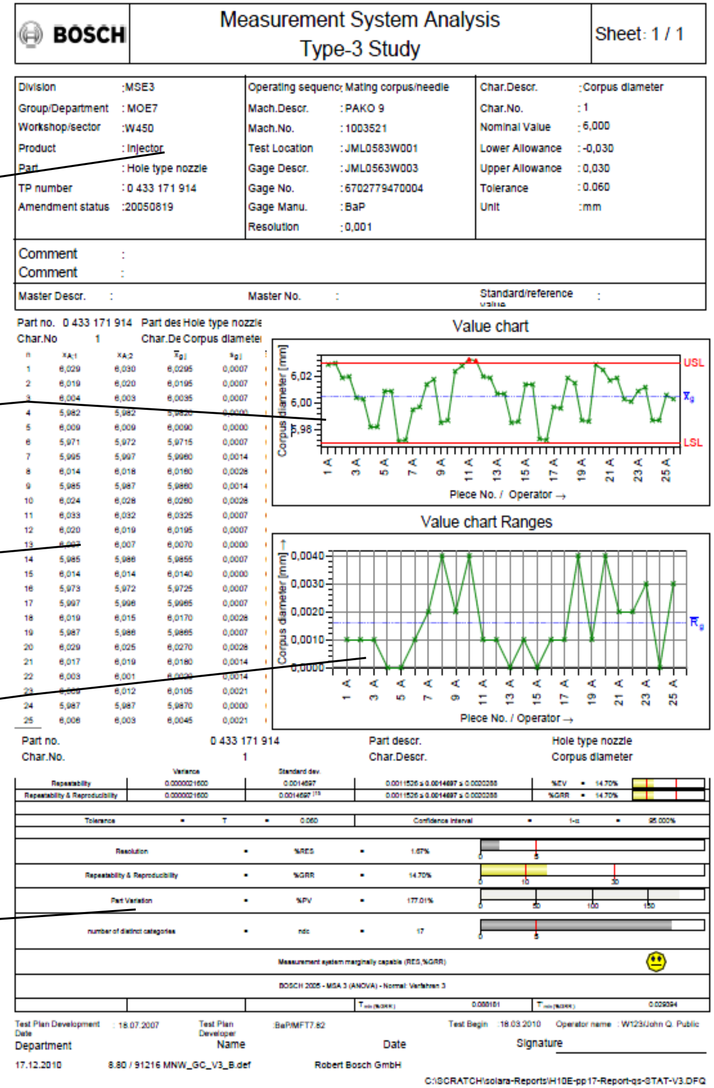
Documentation

Run chart of individual values

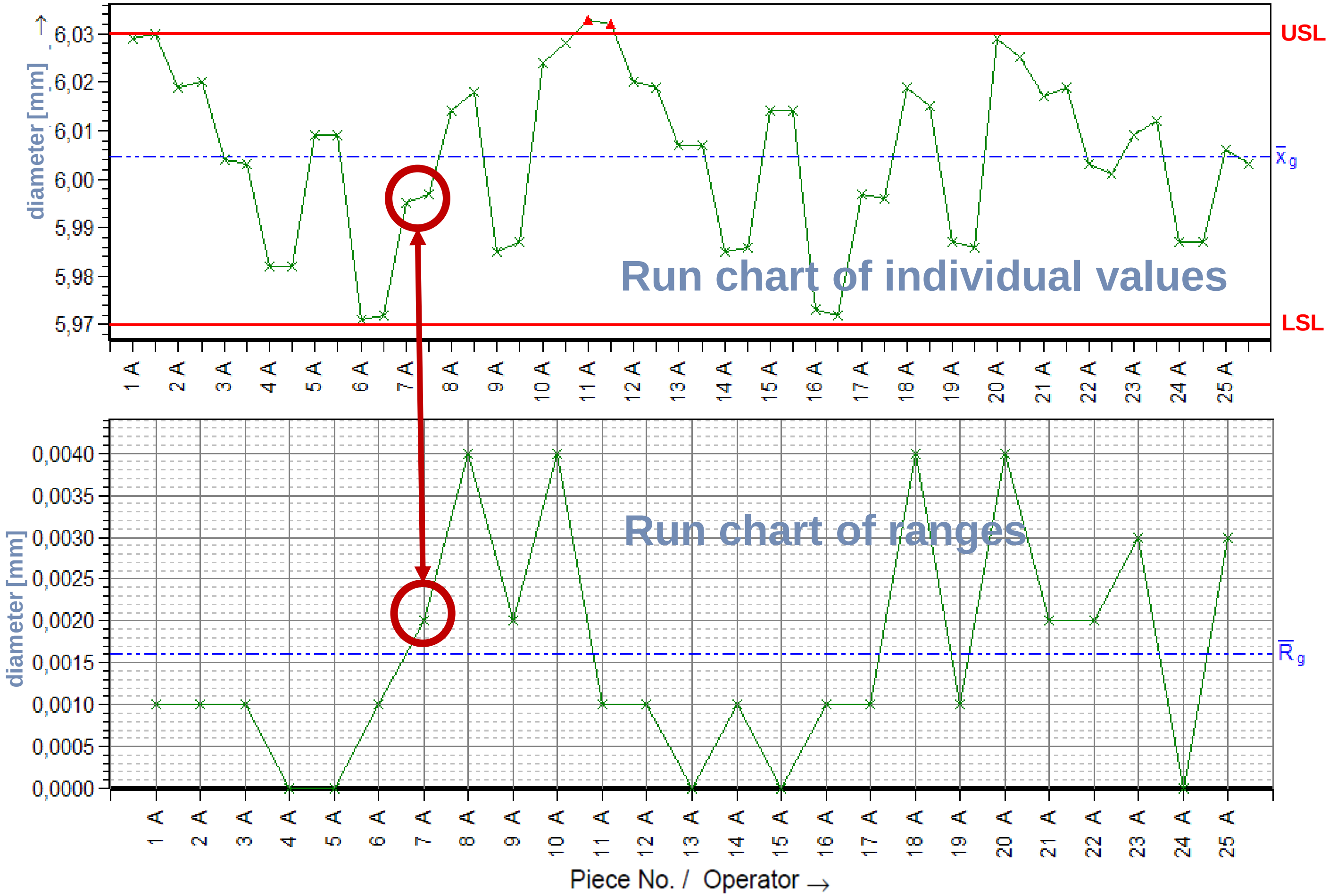
Measurement results

Run chart of ranges

Statistics and assessment



Procedure 3 – Report



Procedure 3 – Calculate statistics

Measurement results

Statistics

n	$x_{A;1}$	$x_{A;2}$	$\bar{x}_{g\,j}$	$s_{g\,j}$
1	6,029	6,030	6,0295	0,0007
2	6,019	6,020	6,0195	0,0007
3	6,004	6,003	6,0035	0,0007
4	5,982	5,982	5,9820	0,0000
5	6,009	6,009	6,0090	0,0000
6	5,971			
7	5,995			
8	6,014			
9	5,985			
10	6,024			
11	6,033			
12	6,020			
13	6,007			
14	5,985			
15	6,014			
16	5,973			
17	5,997			
18	6,019			
19	5,987			
20	6,029			
21	6,017			
22	6,003			
23	6,009			
24	5,987			
25	6,006	6,003	6,0045	0,0021

	Variance	Standard dev.		
Repeatability	0.0000021600	0.0014697	0.0011526 ≤ **0.0014697** ≤ 0.0020288	%EV = 14.70%
Repeatability & Reproducib	0.0000021600	0.0014697)15	0.0011526 ≤ **0.0014697** ≤ 0.0020288	%GRR = 14.70%

Tolerance = T = 0.060 | Confidence interval = 1-α = 95.000%

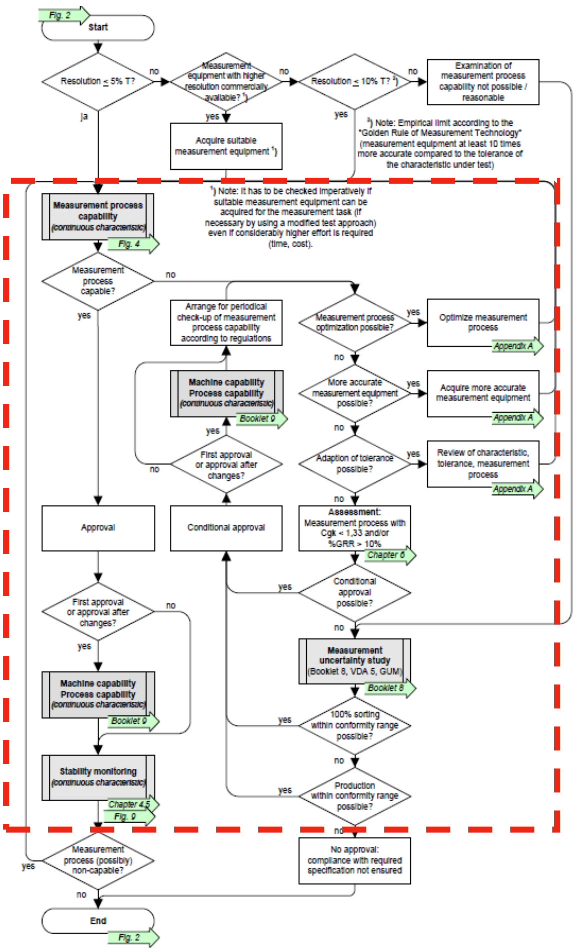
Resolution	=	%RES	=	1.67%	0 5
Repeatability & Reproducibility	=	%GRR	=	14.70%	0 10 30
Part Variation	=	%PV	=	177.01%	0 50 100 150
number of distinct categories	=	ndc	=	17	0 5

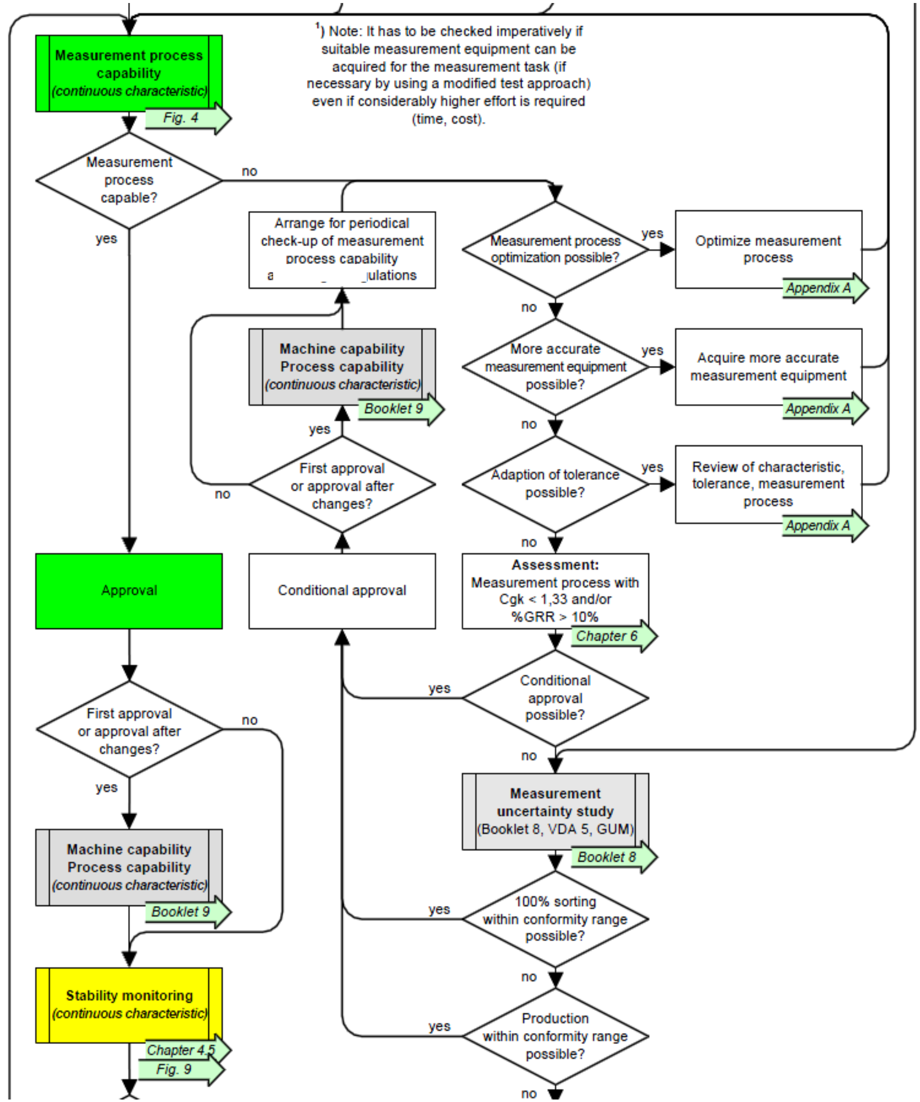
Measurement system marginally capable (RES,%GRR)

Bosch Heft 10 (2003)/MSA 3 (ANOVA) - Normal: Verfahren 3

$T_{min\,(\%GRR)}$ 0.088181 | $T'_{min\,(\%GRR)}$ 0.029394

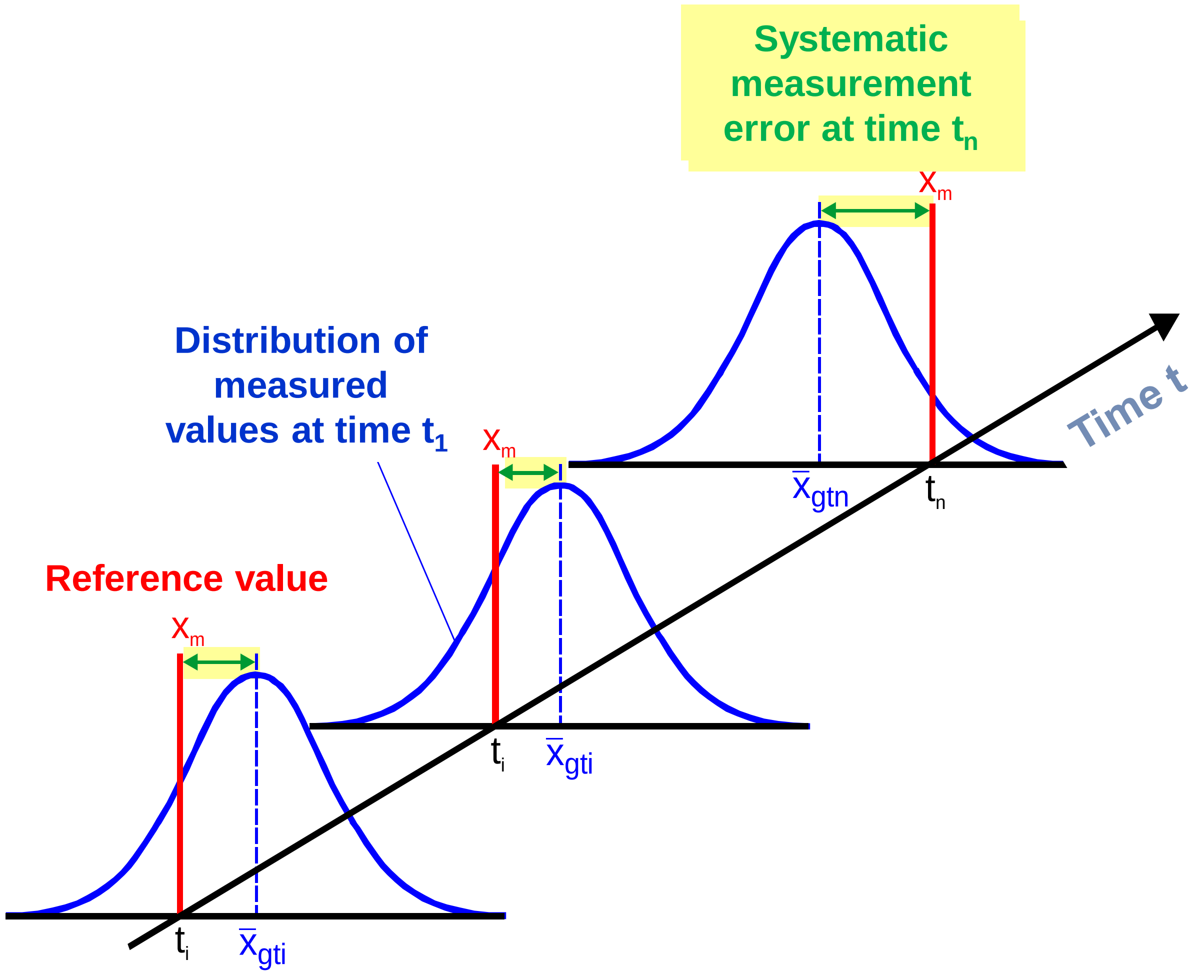
Flow chart





Measurement process capability (continuous characteristic)
Fig. 4
[1]) Note: It has to be checked imperatively if suitable measurement equipment can be acquired for the measurement task (if necessary by using a modified test approach) even if considerably higher effort is required (time, cost).
Measurement process capable?
no
yes
Arrange for periodical check-up of measurement process capability
ulations
Measurement process optimization possible?
yes
Optimize measurement process
Appendix A
no
Machine capability Process capability (continuous characteristic)
Booklet 9
More accurate measurement equipment possible?
yes
Acquire more accurate measurement equipment
Appendix A
no
yes
First approval or approval after changes?
no
Adaption of tolerance possible?
yes
Review of characteristic, tolerance, measurement process
Appendix A
no
Approval
Conditional approval
Assessment: Measurement process with Cgk < 1,33 and/or %GRR > 10%
Chapter 6
yes
Conditional approval possible?
no
First approval or approval after changes?
no
yes
Measurement uncertainty study (Booklet 8, VDA 5, GUM)
Booklet 8
Machine capability Process capability (continuous characteristic)
Booklet 9
yes
100% sorting within conformity range possible?
no
Stability monitoring (continuous characteristic)
Chapter 4.5
Fig. 9
yes
Production within conformity range possible?
no

Procedure 5 – Stability



Procedure 5 – Stability

- **Objective**
  To demonstrate consistent accuracy of results by monitoring long-term performance of a measurement process and conducting a corresponding assessment of the stability of the measuring system (similar to an $\bar{x}$-s control chart)

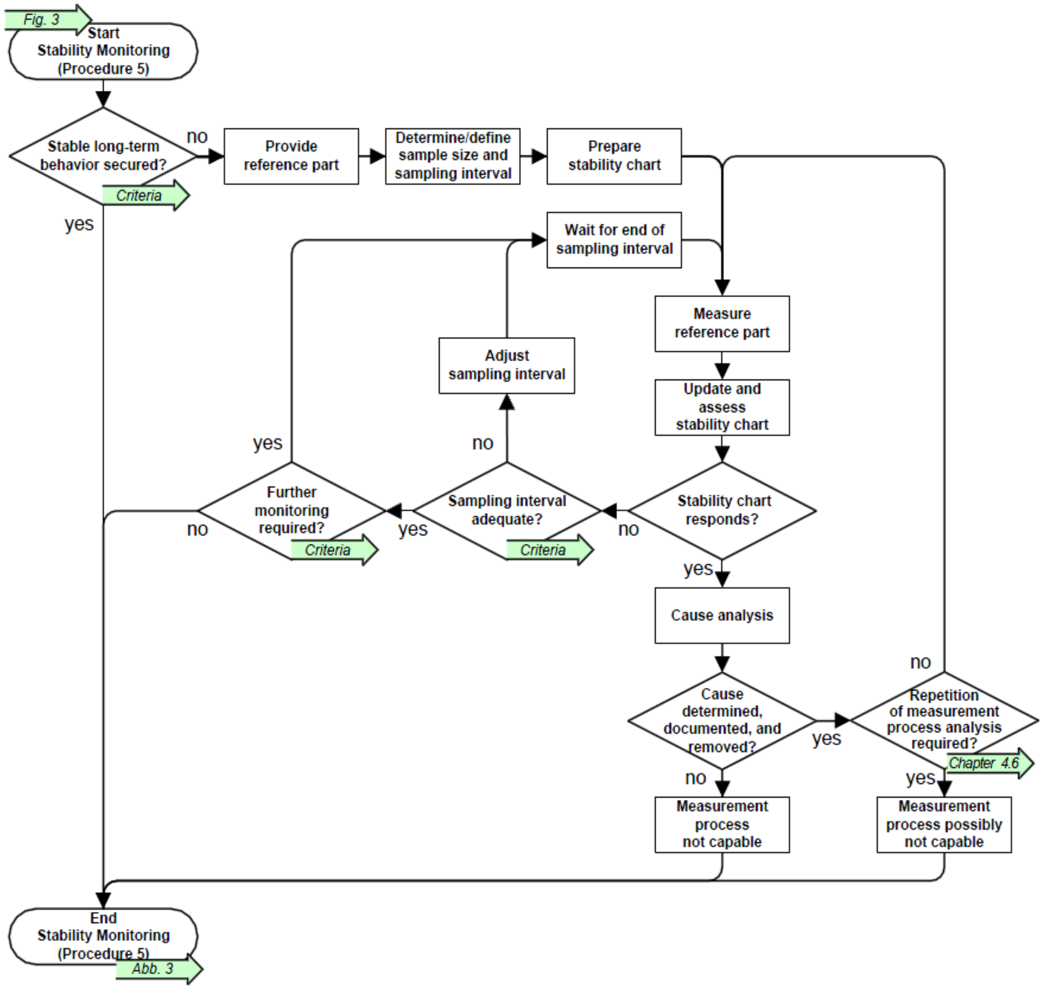
- **Requirements**
  - Stable long-term performance cannot be safely assumed
  - A reference part (measurement standard, or a stable, possibly modified production part) is available (see also requirements for the measurement standard used in procedure 1)

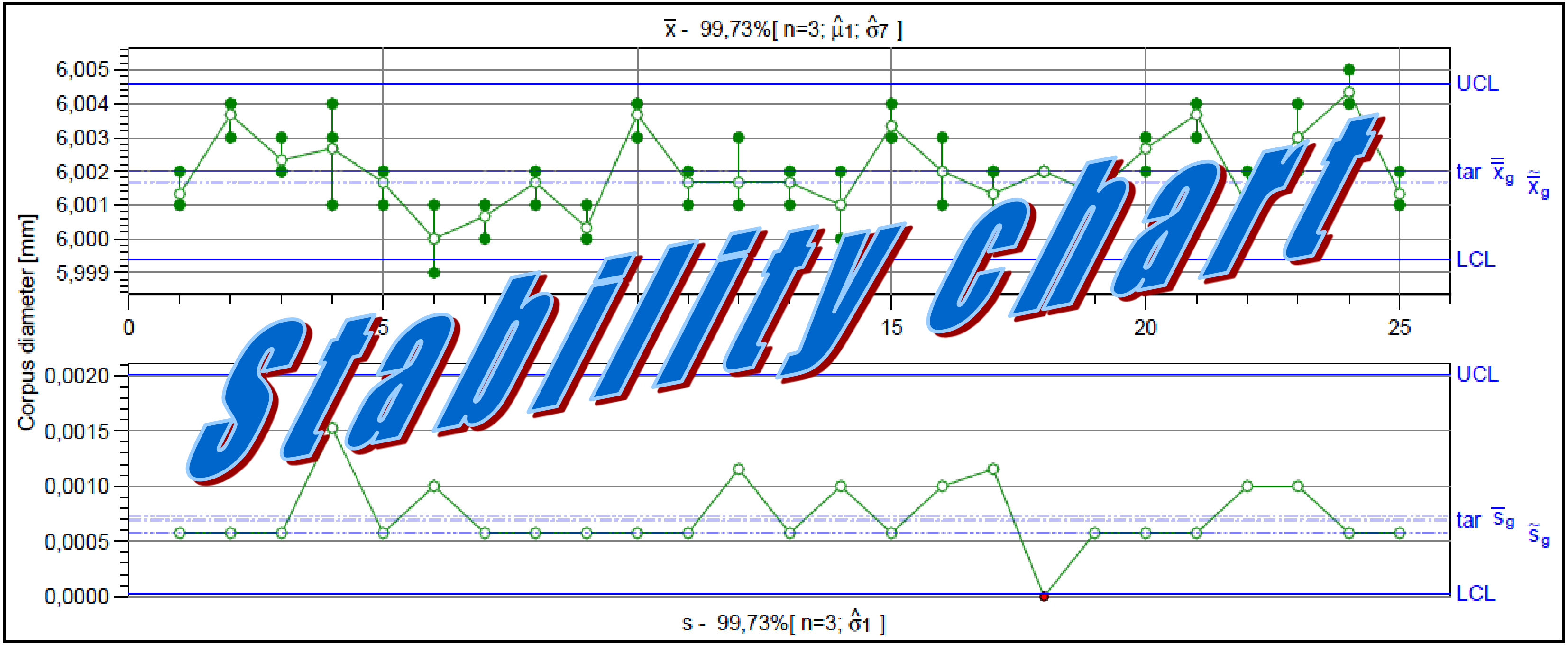
Procedure 5 – Stability

- Conducting the study
  - At least three measurements ($n \geq 3$) of the reference part (stability part) are taken at regular intervals (inspection intervals, sampling intervals), as defined for the specific process.
  - Document the measurement results in the data table of the stability chart.
  - Calculate mean and standard deviation for each sample.
  - Plot the values in their time sequence on the $\bar{x}$/s-chart.
  - The $\bar{x}$-chart can use the actual values or the deviations from the reference value x_m, i.e. the differences between the measurement results and the reference value (residuals).

Procedure 5 – Stability

- Conducting the study





➔ Calculations as for regular control charts

Procedure 5 – Stability chart

Control limits for stability charts

	Lower control limit (LCL)	Upper control limit (UCL)
$\bar{x}$-chart (mean values):	$LCL = x_m - u_p \cdot \frac{s}{\sqrt{n}}$	$UCL = x_m + u_p \cdot \frac{s}{\sqrt{n}}$
s-chart (standard deviations):	$LCL_s = B'_{Eun} \cdot s$	$UCL_s = B'_{Eob} \cdot s$
Individual value chart:	$LCL = x_m - E'_E \cdot s$	$UCL = x_m + E'_E \cdot s$

For x_m the following values can be used:

- the reference value of the reference part (stability part) or
- the mean value of a previous/provisional test run (see [AIAG MSA], chapter 3, paragraph B).

For s the following values can be used:

- 2.5% of the characteristic tolerance T (=T/40) or
- the standard deviation of a previous/provisional test run (see [AIAG MSA], chapter 3, paragraph B).
- the standard deviation from procedure 1 (not recommended because of short-term examination).

The sample size is used for n, i.e. the number of measurements per sample.

u_p, B'_{Eun}, B'_{Eob} and E'_E are used corresponding to the sample size n according to the following table for confidence level 99.73%. For individual value charts, it must be decided how many measured values are combined in one group of the size n (pseudo-sample). n = 3 is well-established.

n	u_p	B'_{Eun}	B'_{Eob}	E'_E
3	3.000	0.037	2.571	3.320
4	3.000	0.100	2.283	3.399
5	3.000	0.163	2.110	3.460

Procedure 5 – Inspection interval

- No fixed rule, depends on the measurement process and its behavior over time
- General principle: begin with short intervals, then lengthen
- Examples of typical criteria for using short intervals:
  - Unstable measurement process
  - Capability indices are close to the limit
  - Characteristic is critical to function or to correct process operation
  - New measurement / test methods
  - No empirical values available
  - High statistical confidence required
  - Timely corrective action must be assured in the event of errors

Procedure 5 – Inspection intervals are …

- … appropriate, if
  - All averages are within the control limits
  - There are visible random changes from value to value

  ⇨ *One control measurement per shift is usually enough*

  ⇨ *If there is long-term stability, the interval may be lengthened*

- … too short, if there are no or only minimal changes from value to value

  ⇨ *However, one control measurement per shift is a must!*

- … too long, if there are values beyond the control limits

Special case: If the equipment is recalibrated or adjusted before each measurement, stability monitoring is not required

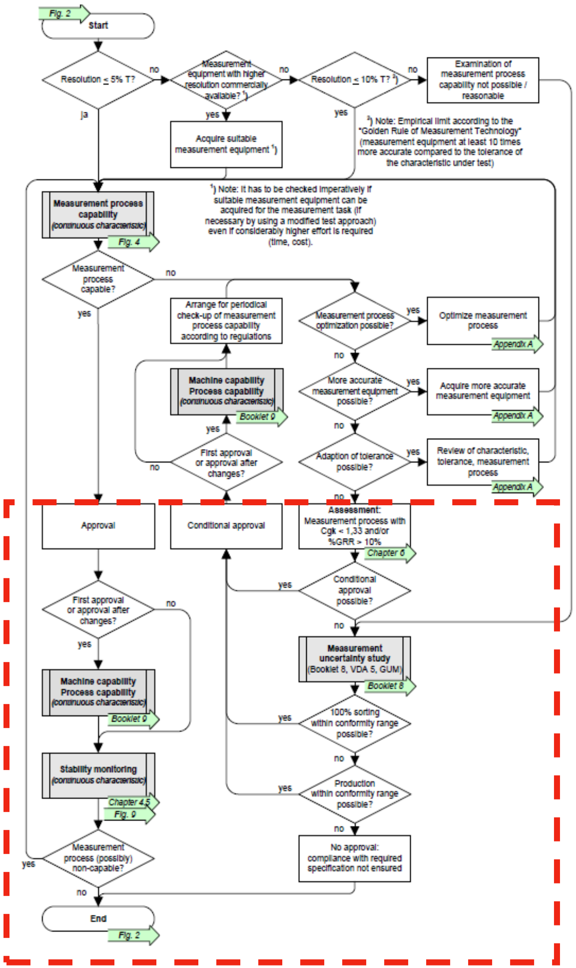
Procedure 5 – Stability criteria

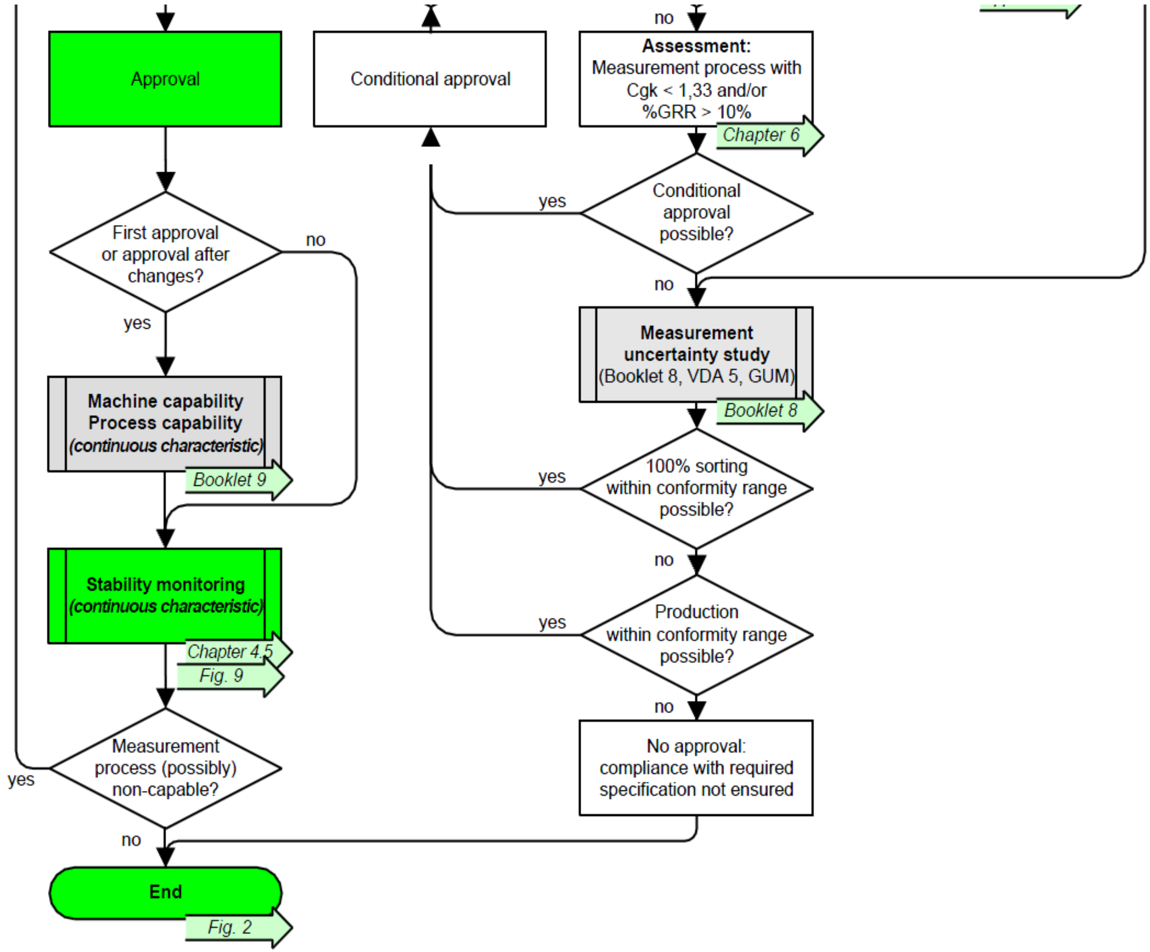
- Stable measurement process
  - All values within the control limits
  - Random variation without special causes

- Unstable measurement process
  - Values beyond the control limits
  - Large random variation over time
  - Signs of special causes
    - Run
    - Trend
    - Middle Third

- If the measurement process is unstable:
  - Identify causes; risk analysis: improvement and re-approval

Flow chart



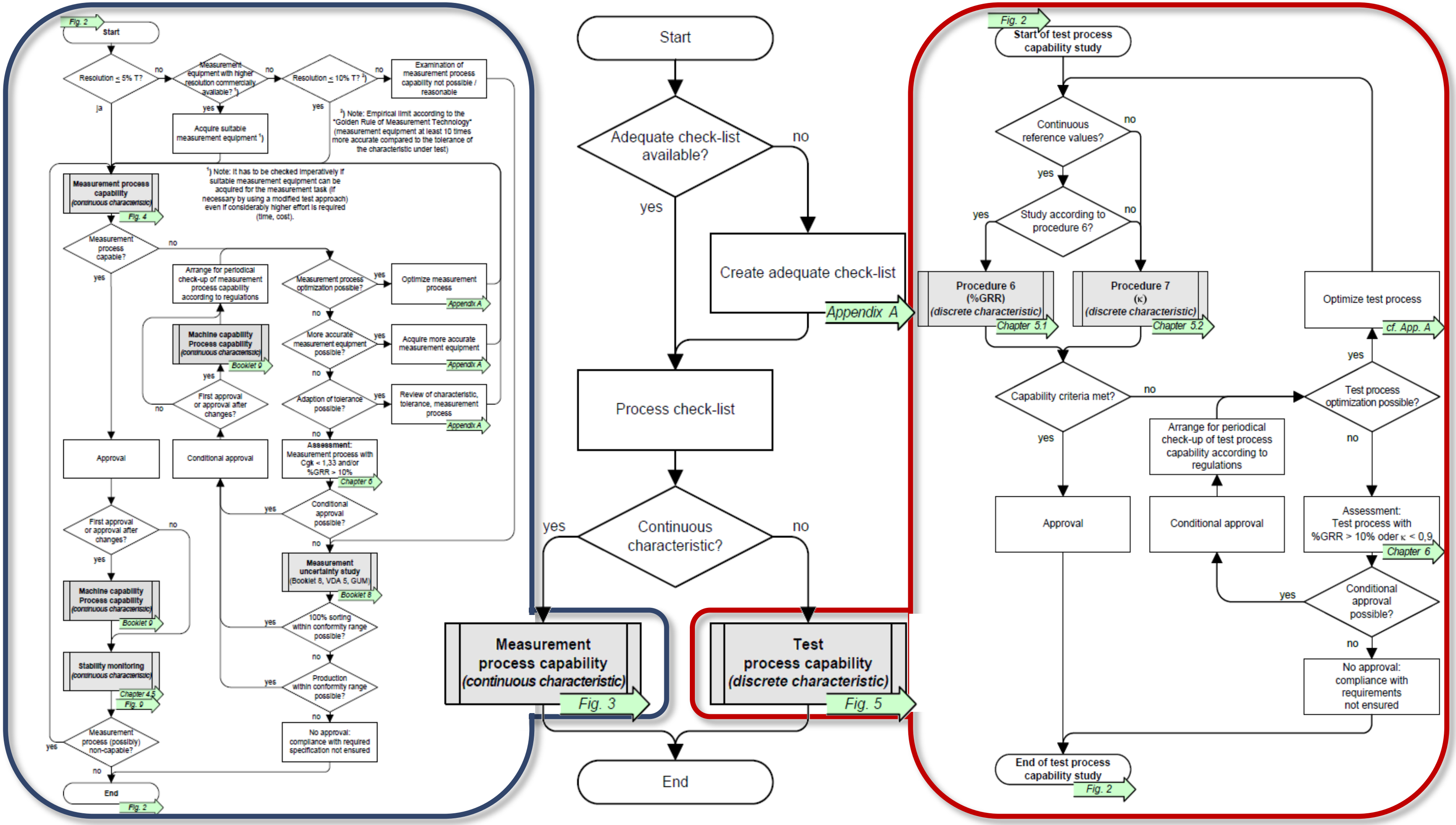


Approval
Conditional approval
no
Assessment:
Measurement process with
Cgk < 1,33 and/or
%GRR > 10%
Chapter 6
First approval
or approval after
changes?
no
yes
Conditional
approval
possible?
yes
no
Machine capability
Process capability
(continuous characteristic)
Booklet 9
Measurement
uncertainty study
(Booklet 8, VDA 5, GUM)
Booklet 8
100% sorting
within conformity range
possible?
yes
no
Stability monitoring
(continuous characteristic)
Chapter 4.5
Fig. 9
Production
within conformity range
possible?
yes
no
Measurement
process (possibly)
non-capable?
yes
no
No approval:
compliance with required
specification not ensured
End
Fig. 2

Repeat demonstration of capability

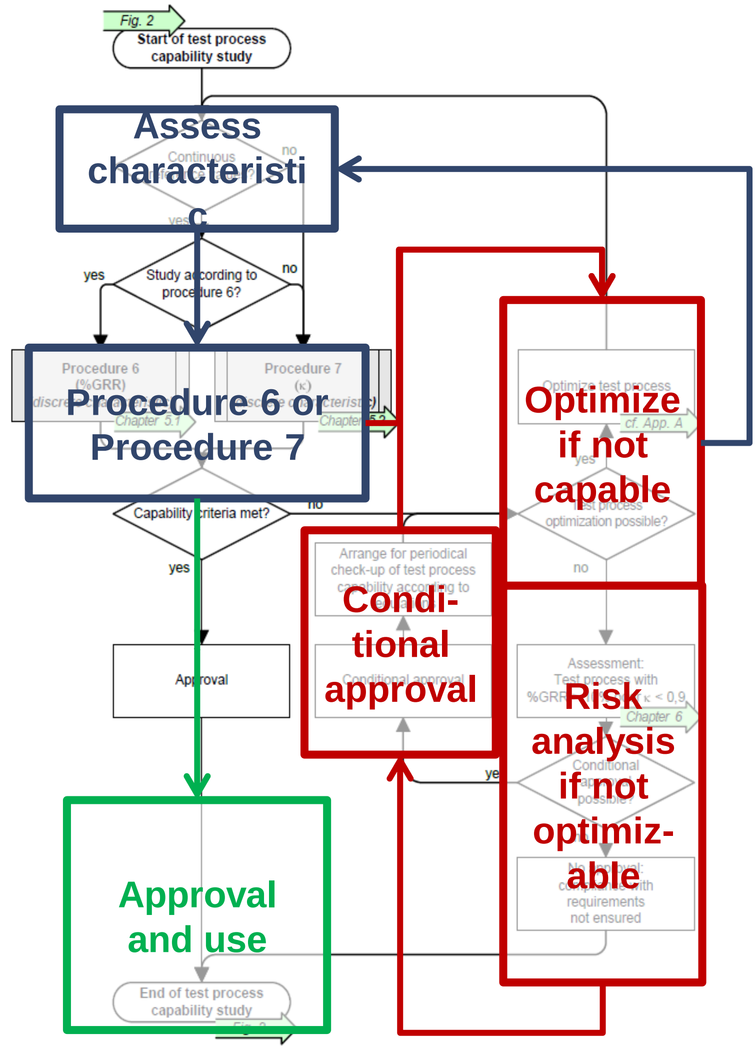
- No defined requirements as for control of inspection, measurement and test equipment!
- "During application in production, the capability of the measurement process must be ensured at all times (preferably using procedure 5)."
- Examples of criteria for re-approval:
  - Significant changes in the stability chart after an intervention
  - Recommissioning after maintenance or repair work etc.
  - Technical changes, significant parameter changes
  - Changes in conditions, environment, staff etc.
  - Before/after relocation
  - Suspected equipment errors
  - …

Methods


Start
Adequate check-list available?
no
yes
Create adequate check-list
Appendix A
Process check-list
Continuous characteristic?
yes
no
Measurement process capability (continuous characteristic)
Fig. 3
Test process capability (discrete characteristic)
Fig. 5
End
Fig. 2
start
Resolution ≤ 5% T?
Measurement equipment with higher resolution commercially available? ¹)
Resolution ≤ 10% T? ²)
Examination of measurement process capability not possible / reasonable
Acquire suitable measurement equipment ¹)
²) Note: Empirical limit according to the "Golden Rule of Measurement Technology" (measurement equipment at least 10 times more accurate compared to the tolerance of the characteristic under test)
¹) Note: It has to be checked imperatively if suitable measurement equipment can be acquired for the measurement task (if necessary by using a modified test approach) even if considerably higher effort is required (time, cost).
Measurement process capability (continuous characteristic)
Fig. 4
Measurement process capable?
Arrange for periodical check-up of measurement process capability according to regulations
Measurement process optimization possible?
Optimize measurement process
Appendix A
Machine capability Process capability (continuous characteristic)
Booklet 9
More accurate measurement equipment possible?
Acquire more accurate measurement equipment
First approval or approval after changes?
Adaption of tolerance possible?
Review of characteristic, tolerance, measurement process
Approval
Conditional approval
Assessment: Measurement process with Cgk < 1,33 and/or %GRR > 10%
Chapter 6
Conditional approval possible?
Measurement uncertainty study (Booklet 8, VDA 5, GUM)
Booklet 8
100% sorting within conformity range possible?
Stability monitoring (continuous characteristic)
Chapter 4.5
Fig. 9
Production within conformity range possible?
Measurement process (possibly) non-capable?
No approval: compliance with required specification not ensured
End
Start of test process capability study
Continuous reference values?
Study according to procedure 6?
Procedure 6 (%GRR) (discrete characteristic)
Chapter 5.1
Procedure 7 (κ) (discrete characteristic)
Chapter 5.2
Optimize test process
cf. App. A
Capability criteria met?
Test process optimization possible?
Arrange for periodical check-up of test process capability according to regulations
Approval
Conditional approval
Assessment: Test process with %GRR > 10% oder κ < 0,9
Conditional approval possible?
No approval: compliance with requirements not ensured
End of test process capability study

Flow chart – Test processes

- Assess characteristic and define study type
- Perform capability analyses
- If capable: use
- If not capable:
  - Optimize
  - Risk analysis
  - Conditional approval and re-qualification



Flow chart

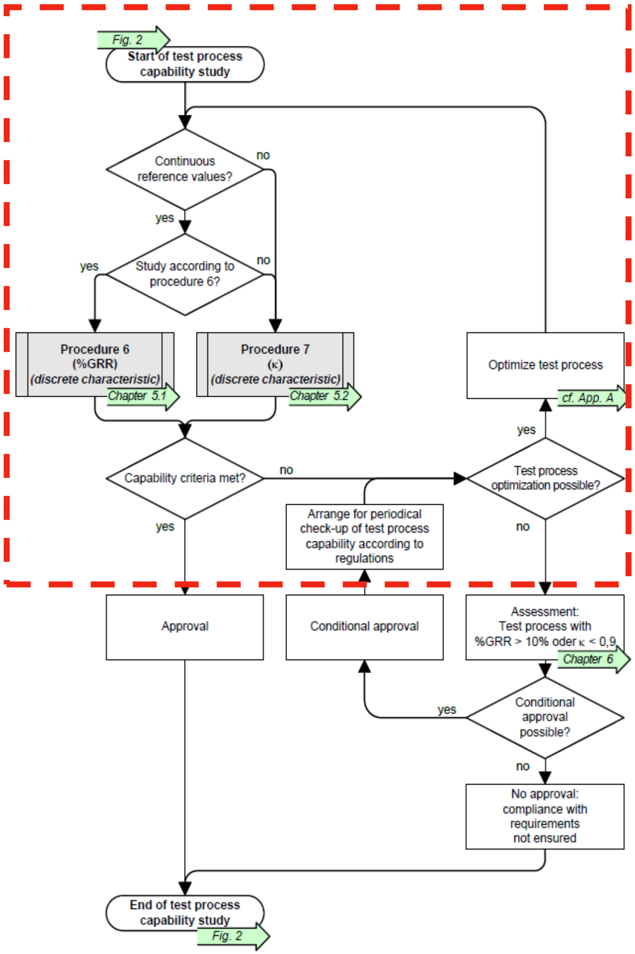


Fig. 2
Start of test process capability study
Continuous reference values?
no
yes
Study according to procedure 6?
yes
no
Procedure 6 (%GRR) (discrete characteristic)
Chapter 5.1
Procedure 7 (κ) (discrete characteristic)
Chapter 5.2
Optimize test process
cf. App. A
yes
Capability criteria met?
no
Test process optimization possible?
Arrange for periodical check-up of test process capability according to regulations
yes
no
Approval
Conditional approval
Assessment: Test process with %GRR > 10% oder κ < 0,9
Chapter 6
yes
Conditional approval possible?
no
No approval: compliance with requirements not ensured
End of test process capability study
Fig. 2

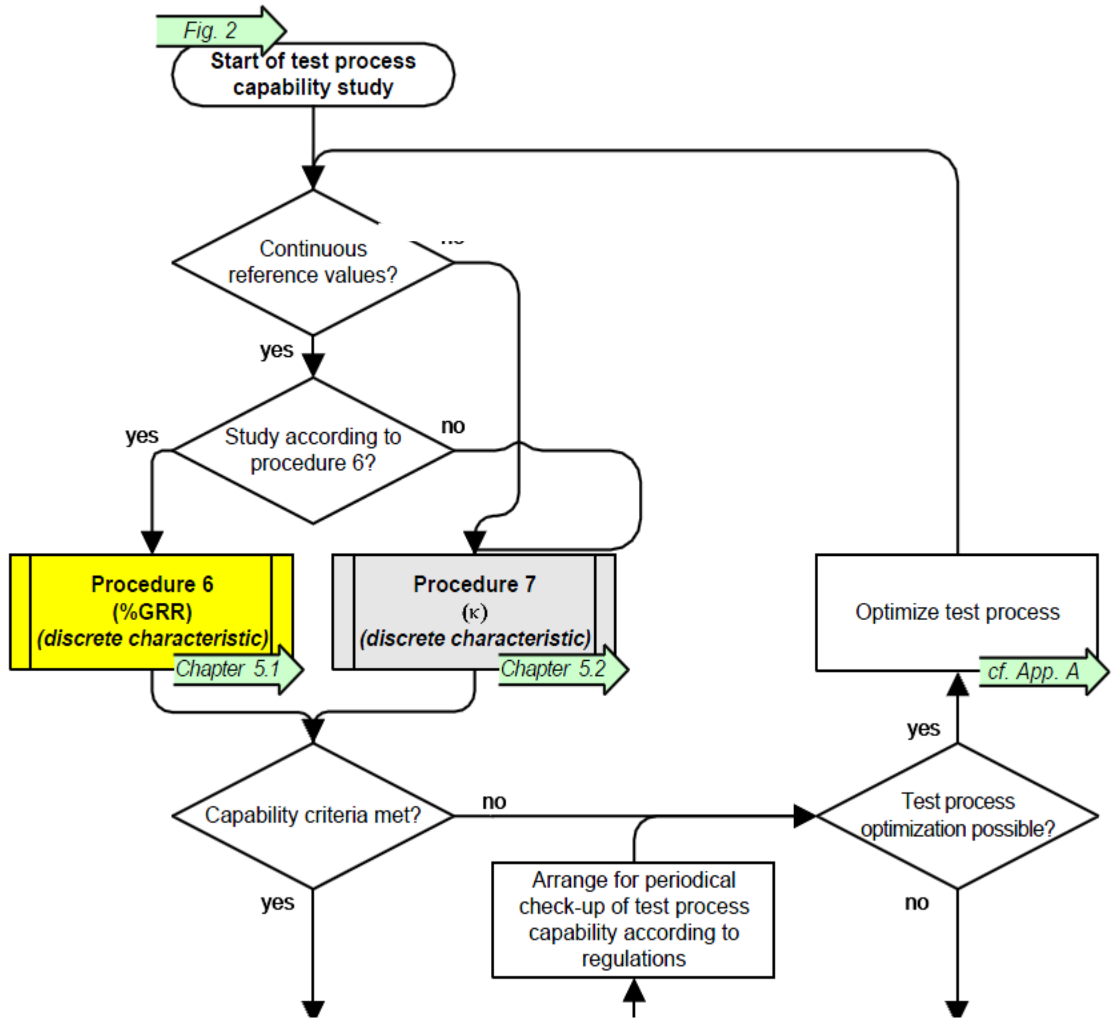
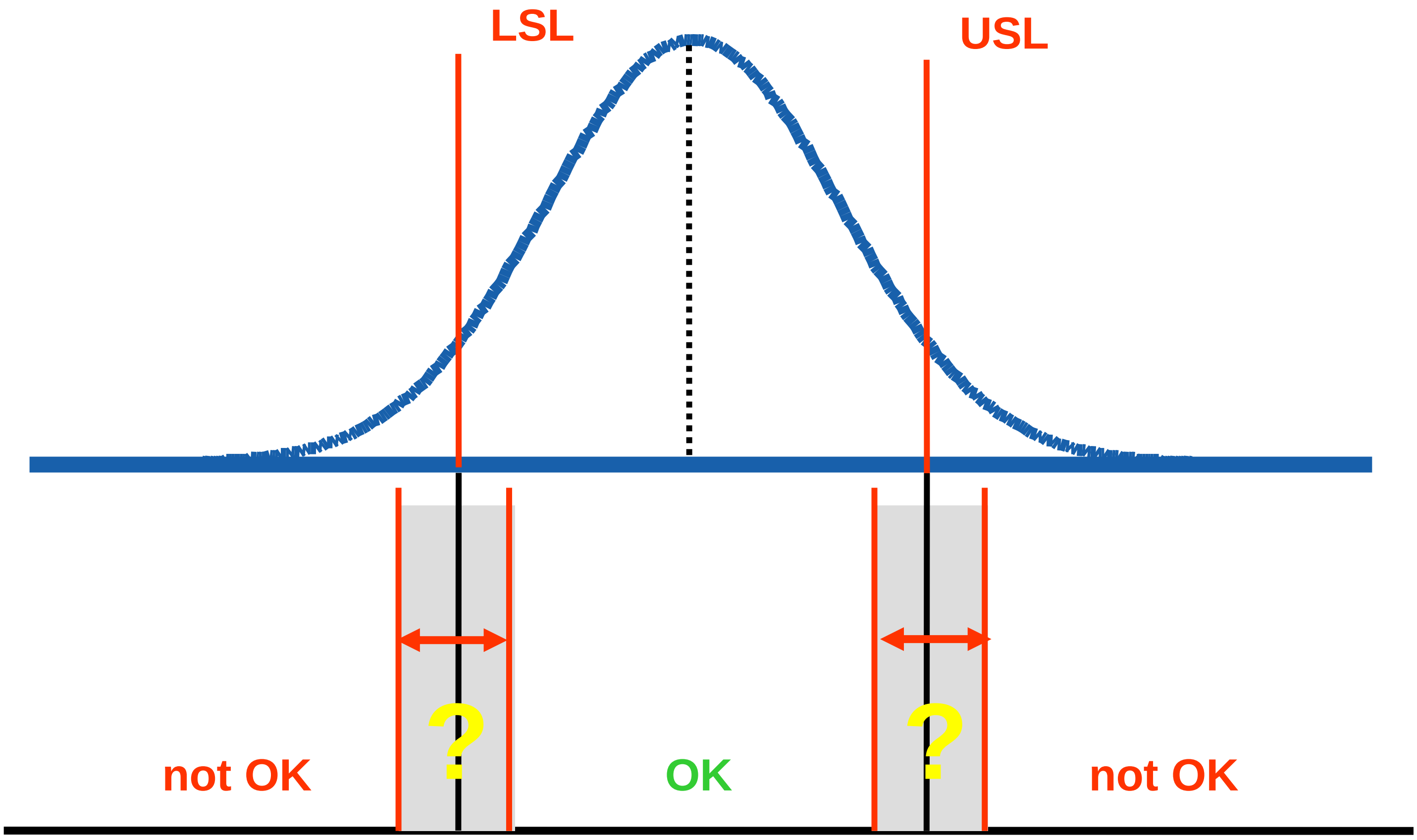


Fig. 2
Start of test process capability study
Continuous reference values?
yes
Study according to procedure 6?
yes
no
Procedure 6 (%GRR) (discrete characteristic)
Chapter 5.1
Procedure 7 (κ) (discrete characteristic)
Chapter 5.2
Optimize test process
cf. App. A
yes
Capability criteria met?
no
Test process optimization possible?
yes
Arrange for periodical check-up of test process capability according to regulations
no

Procedure 6 – Discretized continuous characteristics

- We're looking for the average width of the grey area near USL and LSL



Procedure 6 – Discretized continuous characteristics

- Objective
  To demonstrate the capability of a test process in terms of its ability to deliver unambiguous decisions when testing discretized characteristics.

- Requirements
  - A reference lot made up of 50 reference parts from production (normal production parts), whose discrete characteristic values are determined and documented prior to the start of test.
  - The measurement uncertainty U for the measured values must be known.
  - The characteristic values of the reference parts should cover a range beginning just below LSL – U and ending just above USL + U. The measurement result for each reference part is documented.

Procedure 6 – Discretized continuous characteristics

- Conducting the study
  "Signal detection" method
  - For each gaged characteristic look for …
  - … 50 parts spread out across the tolerance interval (+/- U).
  - Determine a reference value for each part (and for each checked characteristic in case of gages that check several characteristics) in the gage room.
  - Let the parts be checked …
  - … by 2 appraisers …
  - … 2 times each …
  - … in random order.
  - Enter the results in a table.

n	Ref. 1	$x_{A;1}$	$x_{A;2}$	$x_{B;1}$	$x_{B;2}$	
1	3,6320	-	-	+	+	☹
2	3,6490	-	-	-	-	☺
3	3,5870	+	+	+	+	☺
4	3,5520	+	-	-	-	☹
5	3,6210	+	+	+	+	☺
6	3,6450	-	-	-	-	☺
7	3,6520	-	-	-	-	☺
8	3,5990	+	+	+	+	☺
9	3,6340	-	-	-	+	☹
10	3,6250	+	+	+	+	☺
11	3,5720	+	+	+	+	☺
12	3,5520	+	-	-	-	☹
13	3,5950	+	+	+	+	☺
14	3,5610	+	+	-	+	☹
15	3,6170	+	+	+	+	☺
16	3,5850	+	+	+	+	☺
17	3,5310	-	-	-	-	☺
18	3,5820	+	+	+	+	☺
19	3,5440	-	-	-	-	☺
20	3,5740	+	+	+	+	☺
21	3,5950	+	+	+	+	☺
22	3,6420	-	-	-	-	☺
23	3,6210	+	+	+	+	☺
24	3,5650	+	+	-	-	☹
25	3,5930	+	+	+	+	☺
26	3,6220	+	+	+	+	☺
27	3,6320	-	-	+	+	☹
28	3,6640	-	-	-	-	☺
29	3,5460	-	-	-	-	☺
30	3,6520	-	-	-	-	☺
31	3,5860	+	+	+	+	☺
32	3,6410	-	-	+	-	☹
33	3,6140	+	+	+	+	☺
34	3,6000	+	+	+	+	☺
35	3,5910	+	+	+	+	☺
36	3,6320	-	-	+	+	☹
37	3,5700	+	+	+	+	☺
38	3,6030	+	+	+	+	☺
39	3,5780	+	+	+	+	☺
40	3,5970	+	+	+	+	☺
41	3,5870	+	+	+	+	☺
42	3,6140	+	+	+	+	☺
43	3,6130	+	+	+	+	☺
44	3,5920	+	+	+	+	☺
45	3,5600	+	+	-	-	☹
46	3,6260	+	+	+	+	☺
47	3,6320	-	-	+	+	☹
48	3,5730	+	+	+	+	☺
49	3,5590	+	+	-	-	☹
50	3,6090	+	+	+	+	☺

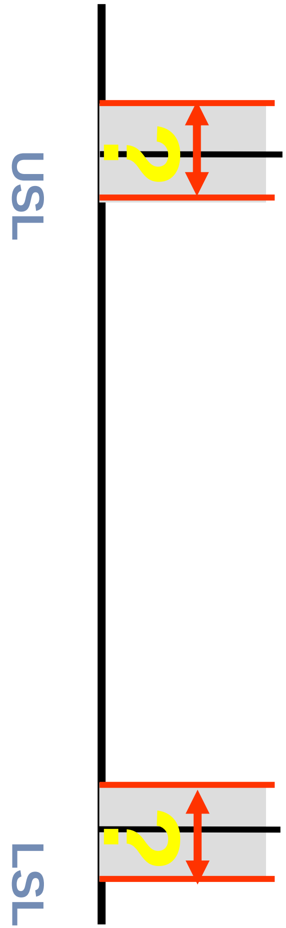
Procedure 6 – Discretized continuous characteristics

n	Ref.	$x_{A;1}$	$x_{A;2}$	$x_{B;1}$	$x_{B;2}$	Result
28	3,6640	−	−	−	−	☺
7	3,6520	−	−	−	−	☺
30	3,6520	−	−	−	−	☺
2	3,6490	−	−	−	−	☺
6	3,6450	−	−	−	−	☺
22	3,6420	−	−	−	−	☺
32	3,6410	−	−	+	−	☹
9	3,6340	−	−	−	+	☹
27	3,6320	−	−	+	+	☹
36	3,6320	−	−	+	+	☹
1	3,6320	−	−	+	+	☹
47	3,6320	−	−	+	+	☹
46	3,6260	+	+	+	+	☺
10	3,6250	+	+	+	+	☺
26	3,6220	+	+	+	+	☺
23	3,6210	+	+	+	+	☺
5	3,6210	+	+	+	+	☺
15	3,6170	+	+	+	+	☺
33	3,6140	+	+	+	+	☺
42	3,6140	+	+	+	+	☺
43	3,6130	+	+	+	+	☺
50	3,6090	+	+	+	+	☺
38	3,6030	+	+	+	+	☺
34	3,6000	+	+	+	+	☺
8	3,5990	+	+	+	+	☺
40	3,5970	+	+	+	+	☺
13	3,5950	+	+	+	+	☺
21	3,5950	+	+	+	+	☺
25	3,5930	+	+	+	+	☺
44	3,5920	+	+	+	+	☺
35	3,5910	+	+	+	+	☺
41	3,5870	+	+	+	+	☺
3	3,5870	+	+	+	+	☺
31	3,5860	+	+	+	+	☺
16	3,5850	+	+	+	+	☺
18	3,5820	+	+	+	+	☺
39	3,5780	+	+	+	+	☺
20	3,5740	+	+	+	+	☺
48	3,5730	+	+	+	+	☺
11	3,5720	+	+	+	+	☺
37	3,5700	+	+	+	+	☺
24	3,5650	+	+	−	−	☹
14	3,5610	+	+	−	+	☹
45	3,5600	+	+	−	−	☹
49	3,5590	+	+	−	−	☹
4	3,5520	+	−	−	−	☹
12	3,5520	+	−	−	−	☹
29	3,5460	−	−	−	−	☺
19	3,5440	−	−	−	−	☺
17	3,5310	−	−	−	−	☺

Sort the results in ascending order according to the reference value

n	Ref.	$x_{A;1}$	$x_{A;2}$	$x_{B;1}$	$x_{B;2}$	Result
1	3,6320	−	−	+	+	☹
2	3,6490	−	−	−	−	☺
3	3,5870	+	+	+	+	☺
4	3,5520	+	−	−	−	☹
5	3,6210	+	+	+	+	☺
6	3,6450	−	−	−	−	☺
7	3,6520	−	−	−	−	☺
8	3,5990	+	+	+	+	☺
9	3,6340	−	−	−	+	☹
10	3,6250	+	+	+	+	☺
11	3,5720	+	+	+	+	☺
12	3,5520	+	−	−	−	☹
13	3,5950	+	+	+	+	☺
14	3,5610	+	+	−	+	☹
15	3,6170	+	+	+	+	☺
16	3,5850	+	+	+	+	☺
17	3,5310	−	−	−	−	☺
18	3,5820	+	+	+	+	☺
19	3,5440	−	−	−	−	☺
20	3,5740	+	+	+	+	☺
21	3,5950	+	+	+	+	☺
22	3,6420	−	−	−	−	☺
23	3,6210	+	+	+	+	☺
24	3,5650	+	+	−	−	☹
25	3,5930	+	+	+	+	☺
26	3,6220	+	+	+	+	☺
27	3,6320	−	−	+	+	☹
28	3,6640	−	−	−	−	☺
29	3,5460	−	−	−	−	☺
30	3,6520	−	−	−	−	☺
31	3,5860	+	+	+	+	☺
32	3,6410	−	−	+	−	☹
33	3,6140	+	+	+	+	☺
34	3,6000	+	+	+	+	☺
35	3,5910	+	+	+	+	☺
36	3,6320	−	−	+	+	☹
37	3,5700	+	+	+	+	☺
38	3,6030	+	+	+	+	☺
39	3,5780	+	+	+	+	☺
40	3,5970	+	+	+	+	☺
41	3,5870	+	+	+	+	☺
42	3,6140	+	+	+	+	☺
43	3,6130	+	+	+	+	☺
44	3,5920	+	+	+	+	☺
45	3,5600	+	+	−	−	☹
46	3,6260	+	+	+	+	☺
47	3,6320	−	−	+	+	☹
48	3,5730	+	+	+	+	☺
49	3,5590	+	+	−	−	☹
50	3,6090	+	+	+	+	☺

Procedure 6 – Discretized continuous characteristics



	Ref.	$x_{A;1}$	$x_{A;2}$	$x_{B;1}$	$x_{B;2}$	
[illegible]	[illegible]	−	−	−	−	☺
7	3,6520	−	−	−	−	☺
30	3,6520	−	−	−	−	☺
2	3,6490	−	−	−	−	☺
6	3,6450	−	−	−	−	☺
22	3,6420	−	−	−	−	☺
32	3,6410	−	−	+	−	☹
9	3,6340	−	−	−	+	☹
27	3,6320	−	−	+	+	☹
36	3,6320	−	−	+	+	☹
1	3,6320	−	−	+	+	☹
47	3,6320	−	−	+	+	☹
46	3,6260	+	+	+	+	☺
10	3,6250	+	+	+	+	☺
26	3,6220	+	+	+	+	☺
23	3,6210	+	+	+	+	☺
5	3,6210	+	+	+	+	☺
15	3,6170	+	+	+	+	☺
33	3,6140	+	+	+	+	☺
42	3,6140	+	+	+	+	☺
43	3,6130	+	+	+	+	☺
50	3,6090	+	+	+	+	☺
38	3,6030	+	+	+	+	☺
34	3,6000	+	+	+	+	☺
8	3,5990	+	+	+	+	☺
40	3,5970	+	+	+	+	☺
13	3,5950	+	+	+	+	☺
21	3,5950	+	+	+	+	☺
25	3,5930	+	+	+	+	☺
44	3,5920	+	+	+	+	☺
35	3,5910	+	+	+	+	☺
41	3,5870	+	+	+	+	☺
3	3,5870	+	+	+	+	☺
31	3,5860	+	+	+	+	☺
16	3,5850	+	+	+	+	☺
18	3,5820	+	+	+	+	☺
39	3,5780	+	+	+	+	☺
20	3,5740	+	+	+	+	☺
48	3,5730	+	+	+	+	☺
11	3,5720	+	+	+	+	☺
37	3,5700	+	+	+	+	☺
24	3,5650	+	+	−	−	☹
14	3,5610	+	+	−	+	☹
45	3,5600	+	+	−	−	☹
49	3,5590	+	+	−	−	☹
4	3,5520	+	−	−	−	☹
12	3,5520	+	−	−	−	☹
29	3,5460	−	−	−	−	☺
19	3,5440	−	−	−	−	☺
17	3,5310	−	−	−	−	☺

d_{USL}

d_{LSL}

$$\%GRR = \frac{\bar{d}}{T} \times 100\%$$

$$\bar{d} = \frac{d_{USL} + d_{LSL}}{2}$$

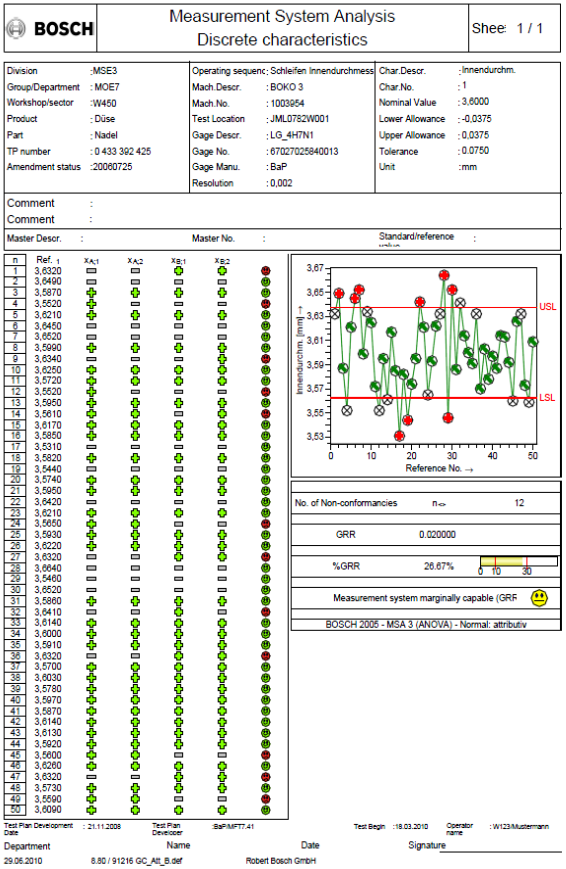
Assessment as per procedure 2:

up to 10% capable

up to 30% conditionally capable

over 30% not capable

Procedure 6 – Discretized continuous characteristics



BOSCH | Measurement System Analysis — Discrete characteristics | Shee: 1 / 1

Division	:MSE3	Operating sequenc	: Schleifen Innendurchmess	Char.Descr.	:Innendurchm.
Group/Department	: MOE7	Mach.Descr.	: BOKO 3	Char.No.	: 1
Workshop/sector	:W450	Mach.No.	: 1003954	Nominal Value	: 3,6000
Product	: Düse	Test Location	: JML0782W001	Lower Allowance	: -0,0375
Part	: Nadel	Gage Descr.	: LG_4H7N1	Upper Allowance	: 0,0375
TP number	: 0 433 392 425	Gage No.	: 67027025840013	Tolerance	: 0.0750
Amendment status	:20060725	Gage Manu.	: BaP	Unit	:mm
		Resolution	: 0,002		

Comment :

Comment :

Master Descr. : Master No. : Standard/reference value :

n	Ref. 1	$x_{A;1}$	$x_{A;2}$	$x_{B;1}$	$x_{B;2}$	
1	3,6320	−	−	+	+	☹
2	3,6490	−	−	−	−	☺
3	3,5870	+	+	+	+	☺
4	3,5520	+	−	−	−	☹
5	3,6210	+	+	+	+	☺
6	3,6450	−	−	−	−	☺
7	3,6520	−	−	−	−	☺
8	3,5990	+	+	+	+	☺
9	3,6340	−	−	−	+	☹
10	3,6250	+	+	+	+	☺
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13	3,5950	+	+	+	+	☺
14	3,5610	+	+	−	+	☹
15	3,6170	+	+	+	+	☺
16	3,5850	+	+	+	+	☺
17	3,5310	−	−	−	−	☺
18	3,5820	+	+	+	+	☺
19	3,5440	−	−	−	−	☺
20	3,5740	+	+	+	+	☺
21	3,5950	+	+	+	+	☺
22	3,6420	−	−	−	−	☺
23	3,6210	+	+	+	+	☺
24	3,5650	+	+	−	−	☹
25	3,5930	+	+	+	+	☺
26	3,6220	+	+	+	+	☺
27	3,6320	−	−	+	+	☹
28	3,6640	−	−	−	−	☺
29	3,5460	−	−	−	−	☺
30	3,6520	−	−	−	−	☺
31	3,5860	+	+	+	+	☺
32	3,6410	−	−	+	−	☹
33	3,6140	+	+	+	+	☺
34	3,6000	+	+	+	+	☺
35	3,5910	+	+	+	+	☺
36	3,6320	−	−	+	+	☹
37	3,5700	+	+	+	+	☺
38	3,6030	+	+	+	+	☺
39	3,5780	+	+	+	+	☺
40	3,5970	+	+	+	+	☺
41	3,5870	+	+	+	+	☺
42	3,6140	+	+	+	+	☺
43	3,6130	+	+	+	+	☺
44	3,5920	+	+	+	+	☺
45	3,5600	+	+	−	−	☹
46	3,6260	+	+	+	+	☺
47	3,6320	−	−	+	+	☹
48	3,5730	+	+	+	+	☺
49	3,5590	+	+	−	−	☹
50	3,6090	+	+	+	+	☺

No. of Non-conformancies $n_{<>}$ 12

GRR 0.020000

%GRR 26.67% (0 10 30)

Measurement system marginally capable (GRR

BOSCH 2005 - MSA 3 (ANOVA) - Normal: attributiv

Test Plan Development Date : 21.11.2008 — Test Plan Developer :BaP/MFT7.41 — Test Begin :18.03.2010 — Operator name : W123/Mustermann

Department — Name — Date — Signature

29.06.2010 — 8.80 / 91216 GC_Att_B.def — Robert Bosch GmbH

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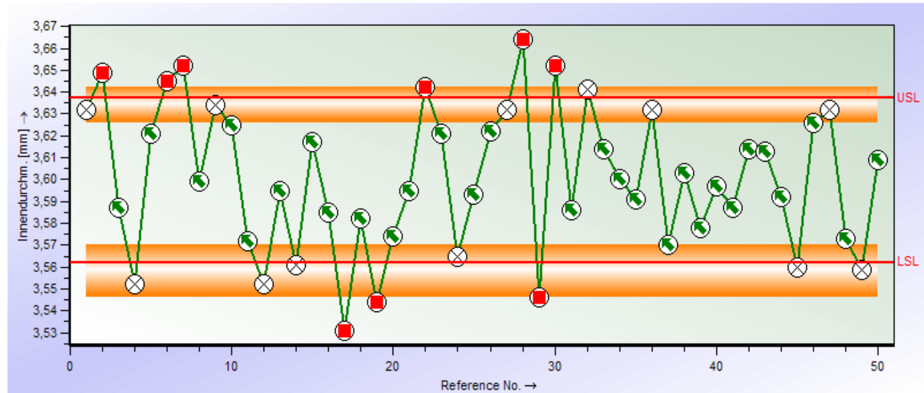


No. of Non-conformancies	$n_{<>}$	12
GRR	0.020000	
%GRR	26.67%	0 10 30
Measurement system marginally capable (GRR)		
Bosch Heft 10 (2003)/MSA 3 (ANOVA) - Normal: attributiv		

Flow chart

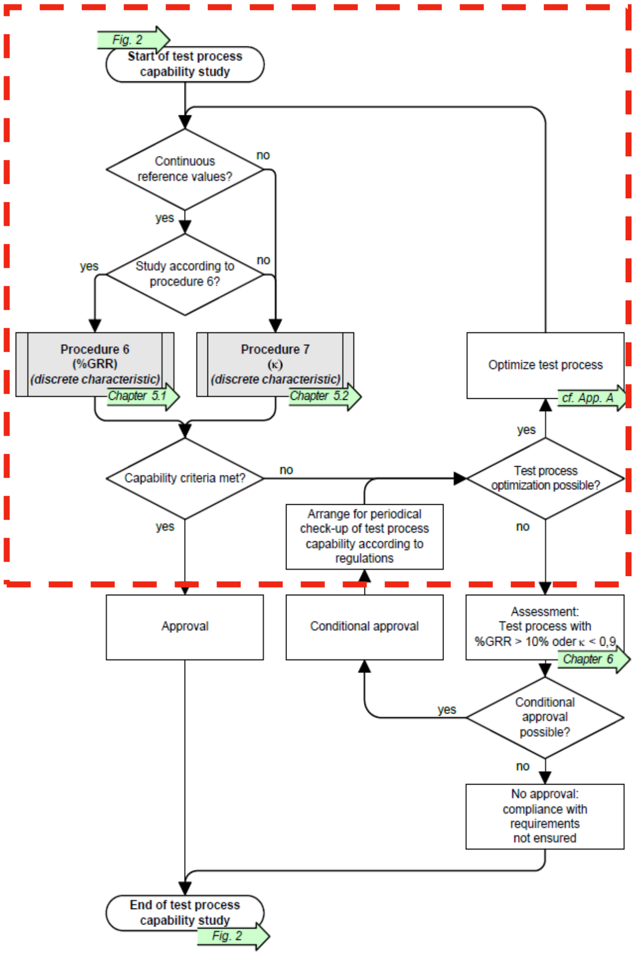


Fig. 2
Start of test process capability study
Continuous reference values?
no
yes
Study according to procedure 6?
yes
no
Procedure 6 (%GRR) (discrete characteristic)
Chapter 5.1
Procedure 7 (κ) (discrete characteristic)
Chapter 5.2
Optimize test process
cf. App. A
yes
Capability criteria met?
no
Test process optimization possible?
yes
Arrange for periodical check-up of test process capability according to regulations
no
Approval
Conditional approval
Assessment: Test process with %GRR > 10% oder κ < 0,9
Chapter 6
Conditional approval possible?
yes
no
No approval: compliance with requirements not ensured
End of test process capability study
Fig. 2

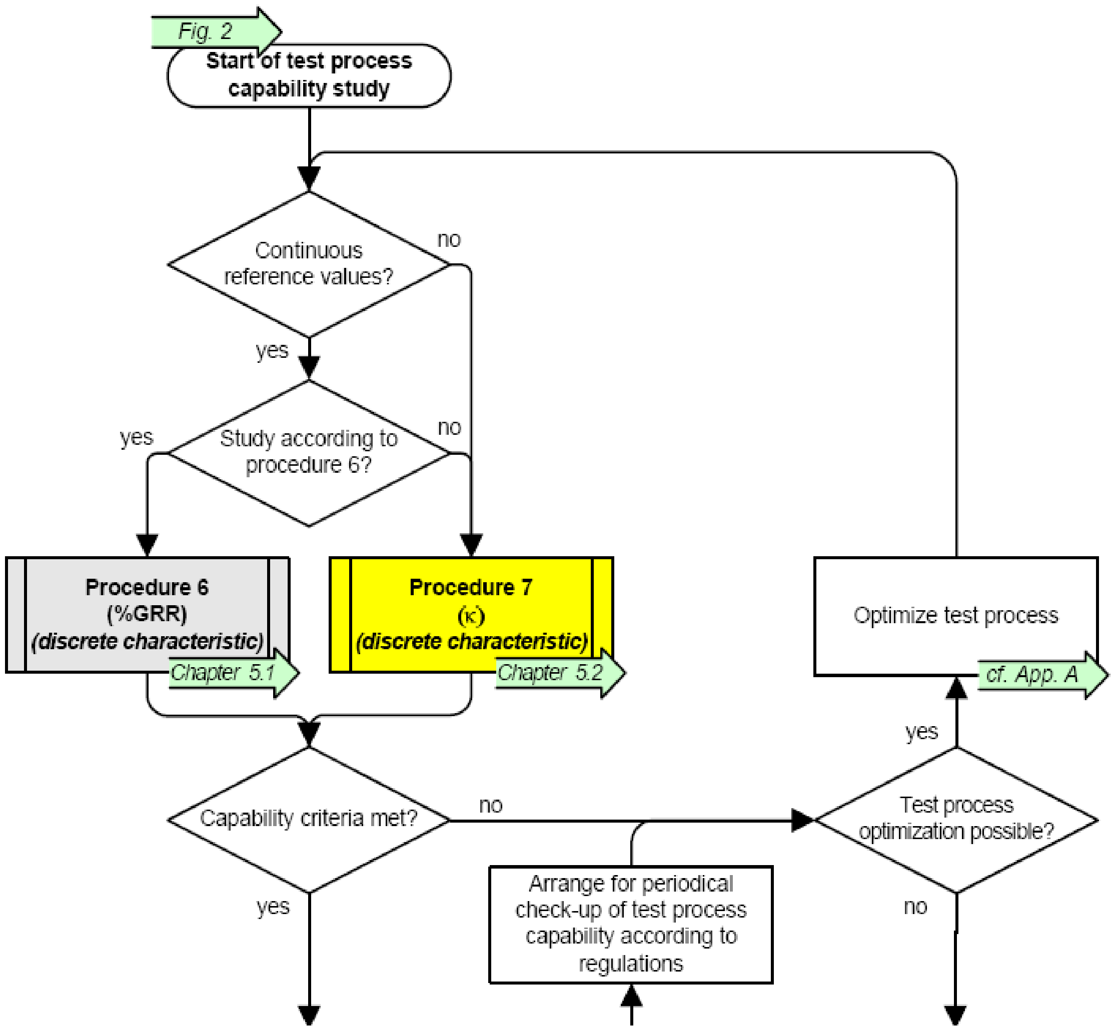


Fig. 2
Start of test process capability study
Continuous reference values?
no
yes
Study according to procedure 6?
yes
no
Procedure 6 (%GRR) (discrete characteristic)
Chapter 5.1
Procedure 7 (κ) (discrete characteristic)
Chapter 5.2
Optimize test process
cf. App. A
yes
Capability criteria met?
no
Test process optimization possible?
yes
Arrange for periodical check-up of test process capability according to regulations
no

Procedure 7 – Discrete characteristics

- Objective
  To assess the capability of a test process in terms of its ability to deliver unambiguous decisions when testing discrete or discretized continuous characteristics.
- Requirements
  Clarify requirements for
  - **Reference parts with continuous characteristics**
    Measurable characteristics subject to (simplified) OK/NOK test
  - **Reference parts with discrete characteristics**
    Characteristics are not measurable, e.g. subjective visual inspection
  - **Reference lot (master)**
    Lot size, composition, identifiability

Procedure 7 – Discrete characteristics

- Requirements for
  Reference parts with continuous characteristics
  - Per procedure 6
- Requirements for
  Reference parts with discrete characteristics
  - Provide reference standards (boundary samples catalog)
  - Assign to categories (OK/NOK)
  - More categories may be possible (grades; scrap/good/rework)
- Requirements for
  Reference lot (master)
  - 100–200 parts are recommended, per AIAG MSA at least 50
  - All relevant properties must be represented in typical proportions
  - All parts are uniquely identifiable (but not visible to the appraiser!)

Procedure 7 – Discrete characteristics

- Conducting the study
  - As in procedure 6 test and categorize the objects in random order under normal operating conditions
  - If appraiser influence is expected: use at least three appraisers and two test runs each
  - If appraiser influence is not expected: use at least six test runs
  - Use a random inspection order, and change it for each run

Procedure 7 – Discrete characteristics

- Analysis
  - Assess pairwise agreement of results, using the Kappa κ statistic

$$\kappa = \frac{\text{Observed non-random agreements}}{\text{Possible non-random agreements}}$$

Calculation details are presented in Appendix G.

The analysis comprises the following comparisons and the calculation of the corresponding statistic κ:

- Within appraisers: compare all test runs of each appraiser without checking against the reference (repeatability).
- Between appraisers: compare all test runs of all appraisers without checking against the reference (reproducibility).
- Compare all test runs of each appraiser against the reference.
- Compare all test runs of all appraisers against the reference.

Deviating from AIAG MSA, the analysis is performed using Fleiss' kappa statistics [Fleiss], which is more generally applicable. If the analysis according to AIAG MSA using Cohen's kappa statistics is explicitly requested (e.g. due to customer requirements), then proceed according to AIAG MSA.

Procedure 7 – Discrete characteristics

- Capability assessment
  Capability is assessed based on the κ statistic ("Kappa"):

  - $\kappa \geq 0.9$: test process capable
  - $0.9 > \kappa \geq 0.7$: test process conditionally capable
  - $\kappa < 0.7$: test process not capable (unsuitable)
  - Use the minimum of all the κ-values for the overall assessment.

Procedure 7 – Discrete characteristics

BOSCH
Quality Management

Test Process Analysis Procedure 7

Record No.: 9911015
Sheet 1 of 2

Product / Test Object

- Product: Housing
- Part: Cover
- Part / Drawing No.: A 111 999 222
- Revision: 05 / 02/29/2009

Characteristic

- Designation: Surface quality
- Characteristic No.: 15
- ☐ Continuous Characteristic
  - Nominal Value: n/a
  - Upper Limit: n/a
  - Lower Limit: n/a
  - Tolerance: n/a
  - Unit: n/a
- ☑ Discrete Characteristic

Measuring & Test Equipment

- Location: XxP/W000999
- Test / Measuring Station: Visual inspection
- Test / Measuring Equipment No.: 123 456 789
- Designation: Boundary samples catalogue
- Calibration Certificate No.: n/a
- Measurement Uncertainty: n/a

Test Method: Visual inspection, manually, room temperature 20.2°C, light intensity 250 cd (Candela)

Test Scenario

- Number of reference parts N_O = 50
- Number of appraisers N_A = 3
- Number of trials per appraiser N_T = 3
- Number of evaluation categories N_C = 2

Evaluation Categories

- 0 - Not OK
- 1 - OK

Test Data: See sheet 2 ff

Analysis

Appraiser name	Symbol	Within appraiser without reference: κ (Kappa)	κ ≥ 0.90 capable	0.70 ≤ κ < 0.90 conditionally capable	κ < 0.70 not capable	Each appraiser against reference: κ (Kappa)	κ ≥ 0.90 capable	0.70 ≤ κ < 0.90 conditionally capable	κ < 0.70 not capable
Miller	A	0.7600		X		0.8802		X	
Smith	B	0.8451		X		0.9226	X		
King	C	0.7029		X		0.7747		X	
		Between appraisers without reference				All appraisers against reference			
all		0.7936		X		0.8592		X	

Total Result

Minimum of all results: Kappa = 0.7029

- Kappa ≥ 0.90: ☐ capable
- 0.70 ≤ Kappa < 0.90: ☑ conditionally capable
- Kappa < 0.70: ☐ not capable

Comment: none

Date: 02/29/2009 Department: W025 Name: J. Q. Public Signature: J. Q. Public

Procedure 7: Test Results — Record No. 9911015, Sheet 2 of 2

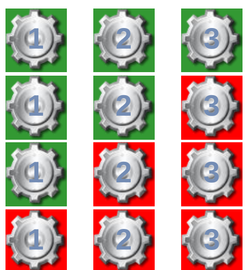
Test Object No.	Reference Value (continuous)	Reference Value (discrete or discretized)	Miller A-1	Miller A-2	Miller A-3	Mayer B-1	Mayer B-2	Mayer B-3	Huber C-1	Huber C-2	Huber C-3			
1	n/a	1	1	1	1	1	1	1	1	1	1			
2	n/a	1	1	1	1	1	1	1	1	1	1			
3	n/a	0	0	0	0	0	0	0	0	0	0			
4	n/a	0	0	0	0	0	0	0	0	0	0			
5	n/a	0	0	0	0	0	0	0	0	0	0			
6	n/a	1	1	1	0	1	1	0	1	0	0			
7	n/a	1	1	1	1	1	1	1	1	0	1			
8	n/a	1	1	1	1	1	1	1	1	1	1			
9	n/a	0	0	0	0	0	0	0	0	0	0			
10	n/a	1	1	1	1	1	1	1	1	1	1			
11	n/a	1	1	1	1	1	1	1	1	1	1			
12	n/a	0	0	0	0	0	0	0	0	1	0			
13	n/a	1	1	1	1	1	1	1	1	1	1			
14	n/a	1	1	1	0	1	1	1	1	0	0			
15	n/a	1	1	1	1	1	1	1	1	1	1			
16	n/a	1	1	1	1	1	1	1	1	1	1			
17	n/a	1	1	1	1	1	1	1	1	1	1			
18	n/a	1	1	1	1	1	1	1	1	1	1			
19	n/a	1	1	1	1	1	1	1	1	1	1			
20	n/a	1	1	1	1	1	1	1	1	1	1			
21	n/a	1	1	1	0	1	0	1	0	1	0			
22	n/a	0	0	0	1	0	1	0	1	1	0			
23	n/a	1	1	1	1	1	1	1	1	1	1			
24	n/a	1	1	1	1	1	1	1	1	1	1			
25	n/a	0	0	0	0	0	0	0	0	0	0			
26	n/a	0	0	1	0	0	0	0	0	0	1			
27	n/a	1	1	1	1	1	1	1	1	1	1			
28	n/a	1	1	1	1	1	1	1	1	1	1			
29	n/a	1	1	1	1	1	1	1	1	1	1			
30	n/a	0	0	0	0	0	0	1	0	0	0			
31	n/a	1	1	1	1	1	1	1	1	1	1			
32	n/a	1	1	1	1	1	1	1	1	1	1			
33	n/a	1	1	1	1	1	1	1	1	1	1			
34	n/a	0	0	0	1	0	0	1	0	1	1			
35	n/a	1	1	1	1	1	1	1	1	1	1			
36	n/a	1	1	1	0	1	1	1	1	0	1			
37	n/a	0	0	0	0	0	0	0	0	0	0			
38	n/a	1	1	1	1	1	1	1	1	1	1			
39	n/a	0	0	0	0	0	0	0	0	0	0			
40	n/a	1	1	1	1	1	1	1	1	1	1			
41	n/a	1	1	1	1	1	1	1	1	1	1			
42	n/a	0	0	0	0	0	0	0	0	0	0			
43	n/a	1	1	0	1	1	1	1	1	1	0			
44	n/a	1	1	1	1	1	1	1	1	1	1			
45	n/a	0	0	0	0	0	0	0	0	0	0			
46	n/a	1	1	1	1	1	1	1	1	1	1			
47	n/a	1	1	1	1	1	1	1	1	1	1			
48	n/a	0	0	0	0	0	0	0	0	0	0			
49	n/a	1	1	1	1	1	1	1	1	1	1			
50	n/a	0	0	0	0	0	0	0	0	0	0			

Evaluation categories: 0 - not OK; 1 - OK

n/a - not applicable

Procedure 7 – Discrete characteristics – Analysis

- Pairwise combinations per appraiser
  - One appraiser checks one part three times
  - Each test result is compared against the other two test results
  - Only agreements are counted



- Agreement 1-2, 1-3, 2-1, 2-3, 3-1, 3-2 → AxA = 6
- Agreement 1-2, 2-1 → AxA = 2
- Agreement 2-3, 3-2 → AxA = 2
- Agreement 1-2, 1-3, 2-1, 2-3, 3-1, 3-2 → AxA = 6

Pairwise combinations are counted according to the same principle

- all appraisers → AxBxC = 44

- each test result of each appraiser
  against the corresponding reference → A1xR = 0 or 2

Number of pair-wise identical combinations per test object i ($i = 1, \dots N_O$)																							
Categories: 0 - Not OK, 1 - OK											A x A	B x B	C x C	A x B x C	A-1 x Ref	A-2 x Ref	A-3 x Ref	B-1 x Ref	B-2 x Ref	B-3 x Ref	C-1 x Ref	C-2 x Ref	C-3 x Ref
Test Object No.	Referenc	Appraiser – Trial																					
		A-1	A-2	A-3	B-1	B-2	B-3	C-1	C-2	C-3													
1	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
2	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
3	0	0	0	0	0	0	0	0	0	0	6	6	6	72	2	2	2	2	2	2	2	2	2
4	0	0	0	0	0	0	0	0	0	0	6	6	6	72	2	2	2	2	2	2	2	2	2
5	0	0	0	0	0	0	0	0	0	0	6	6	6	72	2	2	2	2	2	2	2	2	2
6	1	1	1	0	1	1	0	1	0	0	2	2	2	32	2	2	0	2	2	0	2	0	0
7	1	1	1	1	1	1	1	1	0	1	6	6	2	56	2	2	2	2	2	2	2	0	2
8	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
9	0	0	0	0	0	0	0	0	0	0	6	6	6	72	2	2	2	2	2	2	2	2	2
10	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
11	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
12	0	0	0	0	0	0	0	0	1	0	6	6	2	56	2	2	2	2	2	2	2	0	2
13	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
14	1	1	1	0	1	1	1	1	0	0	2	6	2	36	2	2	0	2	2	2	2	0	0
15	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
16	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
17	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
18	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
19	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
20	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
21	1	1	1	0	1	0	1	0	1	0	2	2	2	32	2	2	0	2	0	2	0	2	0
22	0	0	0	1	0	1	0	1	1	0	2	2	2	32	2	2	0	2	0	2	0	0	2
23	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
24	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
25	0	0	0	0	0	0	0	0	0	0	6	6	6	72	2	2	2	2	2	2	2	2	2
26	0	0	1	0	0	0	0	0	0	1	2	6	2	44	2	0	2	2	2	2	2	2	0

Procedure 7 – Discrete characteristics – Analysis

- From the pairwise combinations determine
  - Sum of all observed decisions that are in agreement
  - Sum of all possible decisions that could be in agreement
  - Percentage of observed decisions that are in agreement

Categories: 0 - Not OK, 1 - OK		Appraiser – Trial									Number of pair-wise identical combinations per test object i (i = 1, … N_O)												
Test Object No.	Reference	A-1	A-2	A-3	B-1	B-2	B-3	C-1	C-2	C-3	A x A	B x B	C x C	A x B x C	A-1 x Ref	A-2 x Ref	A-3 x Ref	B-1 x Ref	B-2 x Ref	B-3 x Ref	C-1 x Ref	C-2 x Ref	C-3 x Ref
1	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
2	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
3	0	0	0	0	0	0	0	0	0	0	6	6	6	72	2	2	2	2	2	2	2	2	2
4	0	0	0	0	0	0	0	0	0	0	6	6	6	72	2	2	2	2	2	2	2	2	2
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
49	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
50	0	0	0	0	0	0	0	0	0	0	6	6	6	72	2	2	2	2	2	2	2	2	2
Observed number of pair-wise identical combinations n^*											268	280	260	3272	100	96	88	100	96	94	96	86	88
Possible number of pair-wise identical combinations N^*											300	300	300	3600	100	100	100	100	100	100	100	100	100
Observed fraction of pair-wise identical combinations $P_{Obs} = n^* / N^*$											0.8933	0.9333	0.8667	0.9089	1.0000	0.9600	0.8800	1.0000	0.9600	0.9400	0.9600	0.8600	0.8800

Procedure 7 – Discrete characteristics – Analysis

- From the individual decisions per part determine
  - Sum and percentage of all OK assessments
  - Sum and percentage of all NOK assessments
  - Assuming these assessments are correct, it is possible to calculate the expected proportion of (random) assessments in agreement

Categories: 0 - Not OK, 1 - OK

Test Object No.	Reference	A-1	A-2	A-3	B-1	B-2	B-3	C-1	C-2	C-3	A x A	B x B	C x C	A x B x C	A-1 x Ref	A-2 x Ref	A-3 x Ref	B-1 x Ref	B-2 x Ref	B-3 x Ref	C-1 x Ref	C-2 x Ref	C-3 x Ref
1	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
2	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
3	0	0	0	0	0	0	0	0	0	0	6	6	6	72	2	2	2	2	2	2	2	2	2

Number of pair-wise identical combinations per test object i (i = 1, … N_O)

	A x A	B x B	C x C	A x B x C	A-1 x Ref	A-2 x Ref	A-3 x Ref	B-1 x Ref	B-2 x Ref	B-3 x Ref	C-1 x Ref	C-2 x Ref	C-3 x Ref
Observed number of evaluations per category n_k (k = 1, … N_C)	50 100	47 103	51 99	148 302	32 68	32 68	34 66	32 68	32 68	31 69	32 68	33 67	34 66
Total number of evaluations N	150	150	150	450	100	100	100	100	100	100	100	100	100
Observed fraction of evaluations per category n_k / N (k = 1, … N_C)	0.3333 0.6667	0.3133 0.6867	0.34 0.66	0.3289 0.6711	0.32 0.68	0.32 0.68	0.34 0.66	0.32 0.68	0.32 0.68	0.31 0.69	0.32 0.68	0.33 0.67	0.34 0.66
Expected fraction of randomly identical evaluations $P_{Exp} = \Sigma_k (n_k/N)^2$	0.5556	0.5697	0.5512	0.5586	0.5648	0.5648	0.5512	0.5648	0.5648	0.5722	0.5648	0.5578	0.5512

Procedure 7 – Discrete characteristics – Analysis

- Calculate a kappa value from the observed and expected percentages

  - The difference between the observed agreements P_{Obs} and the expected (random) agreements P_{Exp} yields the proportion of "observed non-random agreements" $P_{Obs} - P_{Exp}$

  - The difference between the expected (random) agreements P_{Exp} and 100% yields the proportion of "possible non-random agreements" $1-P_{Exp}$

$$\kappa = \frac{P_{Obs} - P_{Exp}}{1 - P_{Exp}} = \frac{\text{Observed non-random agreements}}{\text{Possible non-random agreements}}$$

- Calculate the kappa values, use respective mean values for the assessment of agreement with the reference

Categories: 0 - Not OK, 1 - OK											Number of pair-wise identical combinations per test object i (i = 1, … N_O)												
Test Object No.	Reference	Appraiser – Trial: A-1	A-2	A-3	B-1	B-2	B-3	C-1	C-2	C-3	A x A	B x B	C x C	A x B x C	A-1 x Ref	A-2 x Ref	A-3 x Ref	B-1 x Ref	B-2 x Ref	B-3 x Ref	C-1 x Ref	C-2 x Ref	C-3 x Ref
1	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
2	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
3	0	0	0	0	0	0	0	0	0	0	6	6	6	72	2	2	2	2	2	2	2	2	2
4	0	0	0	0	0	0	0	0	0	0	6	6	6	72	2	2	2	2	2	2	2	2	2
[illegible]	0	0	0	0	0	0	0	0	0	0	6	6	6	72	2	2	2	2	2	2	2	2	2
49	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	2	2	2	2	2	2	2	2
50	0	0	0	0	0	0	0	0	0	0	6	6	6	72	2	2	2	2	2	2	2	2	2
Observed fraction of pair-wise identical combinations $P_{Obs} = n^* / N^*$											0.8933	0.9333	0.8667	0.9089	1.0000	0.9600	0.8800	1.0000	0.9600	0.9400	0.9600	0.8600	0.8800
Expected fraction of randomly identical evaluations $P_{Exp} = \Sigma_k (n_k/N)^2$											0.5556	0.5697	0.5512	0.5586	0.5648	0.5648	0.5512	0.5648	0.5648	0.5722	0.5648	0.5578	0.5512
Kappa: $\frac{P_{Obs} - P_{Exp}}{1 - P_{Exp}} = \kappa$											0.7600	0.8451	0.7029	0.7936	1.0000	0.9081	0.7326	1.0000	0.9081	0.8597	0.9081	0.6834	0.7326
Kappa: Each appraiser against reference (mean values)															0.8802			0.9226			0.7747		
Kappa: All appraisers against reference (mean value)															0.8592								

Procedure 7 – Discrete characteristics – Analysis

➔ The smallest kappa value determines the overall result

	A x A	B x B	C x C	A x B x C	A-1 x Ref	A-2 x Ref	A-3 x Ref	B-1 x Ref	B-2 x Ref	B-3 x Ref	C-1 x Ref	C-2 x Ref	C-3 x Ref
	Number of pair-wise identical combinations per test object i (i = 1, … N_O)												
Categories: 0 - Not OK, 1 - OK													
Test object No. / Reference / Appraiser – Trial: A-1, A-2, A-3, B-1, B-2, B-3, C-1, C-2, C-3													
Kappa: $\frac{P_{Obs} - P_{Exp}}{1 - P_{Exp}} = \kappa$	0.7600	0.8451	0.7029	0.7936	1.0000	0.9081	0.7326	1.0000	0.9081	0.8597	0.9081	0.6834	0.7326
Kappa: Each appraiser against reference (mean values)					0.8802			0.9226			0.7747		
Kappa: All appraisers against reference (mean value)								0.8592					

Appraiser name	Symbol	κ (Kappa)	κ ≥ 0.90 capable	0.70 ≤ κ < 0.90 conditionally capable	κ < 0.70 not capable	κ (Kappa)	κ ≥ 0.90 capable	0.70 ≤ κ < 0.90 conditionally capable	κ < 0.70 not capable
Miller	*A*	*0.7600*		X		*0.8802*		X	
Smith	*B*	*0.8451*		X		*0.9226*	X		
King	*C*	*0.7029*		X		*0.7747*		X	
		Between appraisers without reference				All appraisers against reference			
all		*0.7936*		X		*0.8592*		X	

Total Result — Minimum of all results: Kappa = *0.7029*

Kappa ≥ 0.90: ☐ capable — 0.70 ≤ Kappa < 0.90: ☑ conditionally capable — Kappa < 0.70: ☐ not capable

Procedure 7 – Discrete characteristics

BOSCH Quality Management

Test Process Analysis Procedure 7

Record No.: *9911015*

Sheet *1* of *2*

Product / Test Object		Characteristic		Measuring & Test Equipment	
Product:	*Housing*	Designation:	*Surface quality*	Location:	*XxP/W000999*
Part:	*Cover*	Characteristic No.:	*15*	Test / Measuring Station:	*Visual inspection*
Part / Drawing No.:	*A 111 999 222*	☐ **Continuous Characteristic**		Test / Measuring Equipment No.:	*123 456 789*
Revision:	*05 / 02/29/2009*	Nominal Value:	*n/a*	Designation:	*Boundary samples catalogue*
		Upper Limit:	*n/a*	Calibration Certificate No.:	*n/a*
		Lower Limit:	*n/a*	Measurement Uncertainty:	*n/a*
		Tolerance:	*n/a*		
		Unit:	*n/a*		
		☑ **Discrete Characteristic**			

Test Method: *Visual inspection, manually, room temperature 20.2°C, light intensity 250 cd (Candela)*

Test Scenario				Evaluation Categories
Number of reference parts	N_O	=	*50*	*0 - Not OK*
Number of appraisers	N_A	=	*3*	*1 - OK*
Number of trials per appraiser	N_T	=	*3*	
Number of evaluation categories	N_C	=	*2*	

Test Data: *See sheet 2 ff*

Analysis

Appraiser name	Symbol	Within appraiser without reference: κ (Kappa)	κ ≥ 0.90 capable	0.70 ≤ κ < 0.90 conditionally capable	κ < 0.70 not capable	(Ka
Miller	*A*	*0.7600*		*X*		*0.8*
Smith	*B*	*0.8451*		*X*		*0.9*
King	*C*	*0.7029*		*X*		*0.7*
		Between appraisers without reference				
all		*0.7936*		*X*		*0.8*

Total Result

Kappa ≥ 0.90: ☐ capable

Minimum of all results: 0.70 ≤ Kappa < 0.90: ☑ conditionally capable

Comment: *none*

Date: *02/29/2009* Department: *W025* Name: *J. Q. Public* Signa

BOSCH Quality Management

Test Process Analysis Procedure 7

Product / Test Object		Characteristic	
Product:	*Housing*	Designation:	*Surface quality*
Part:	*Cover*	Characteristic No.:	*15*
Part / Drawing No.:	*A 111 999 222*	☐ Continuous Characteristic	
Revision:	*05 / 02/29/2009*	Nominal Value:	*n/a*
		Upper Limit:	*n/a*
		Lower Limit:	*n/a*
		Tolerance:	*n/a*
		Unit:	*n/a*
		☑ Discrete Characteristic	

Mea… Loca… Test… Statio… Test… Equip… Desig… Calib… Certi… Meas… Unce…

Test Method: *Visual inspection, manually, room temperature 20.2ºC, light intens…*

Test Scenario			Evaluation Categories
Number of reference parts	N_R =	*50*	*0 - Not OK*
Number of appraisers	N_A =	*3*	*1 - OK*
Number of trials per appraiser	N_T =	*3*	
Number of evaluation categories	N_C =	*2*	

Test Data: *See sheet 2 ff*

Analysis

Appraiser name	Symbol	Within appraiser without reference: κ (Kappa)	κ ≥ 0.90 capable	0.70 ≤ κ < 0.90 conditionally capable	κ < 0.70 not capable	Each appraiser against reference: κ (Kappa)	κ ≥ 0.90 capable	0.70 ≤ κ < 0.90 conditionally capable	κ < 0.70 not capable
Miller	*A*	*0.7600*		*X*		*0.8802*		*X*	
Smith	*B*	*0.8451*		*X*		*0.9226*	*X*		
King	*C*	*0.7029*		*X*		*0.7747*		*X*	
		Between appraisers without reference				**All appraisers against reference**			
all		*0.7936*		*X*		*0.8592*		*X*	

Total Result

Minimum of all results: Kappa = *0.7029*

Kappa ≥ 0.90: ☐ capable

0.70 ≤ Kappa < 0.90: ☑ conditionally capable

Kappa < 0.70: ☐ not capable

Comment: *none*

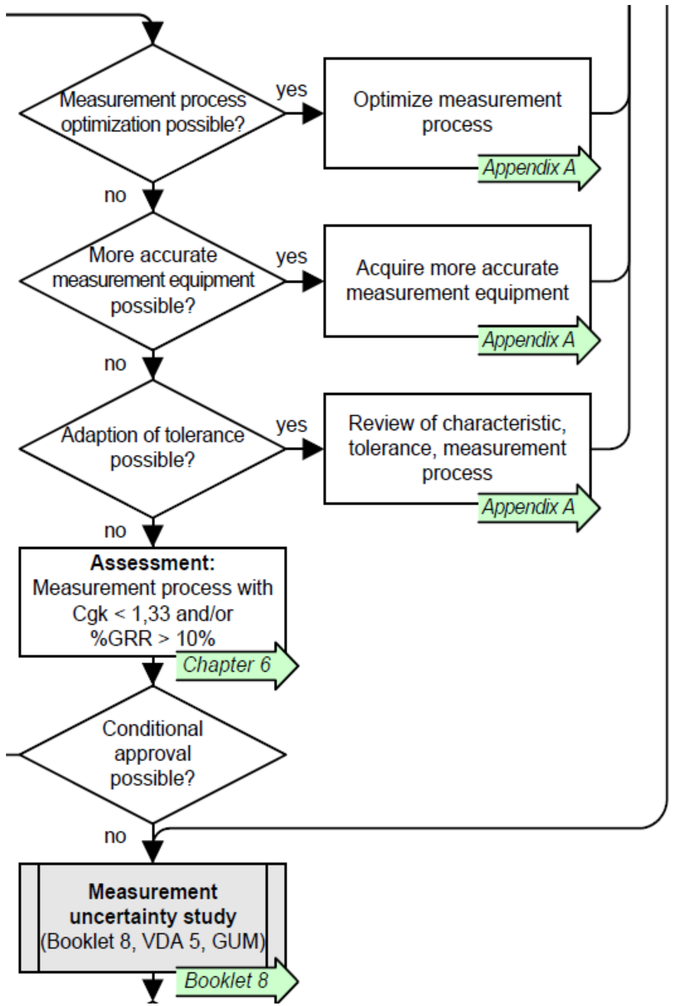
Date: *02/29/2009* Department: *W025* Name: *J. Q. Public* Signature: *J. Q. Public*

Test Data: See sheet 2 ff
Analysis
Miller A 0.7600 X 0.88…
Smith B 0.8451 X 0.92…
King C 0.7029 X 0.77…
all 0.7936 X 0.85…
Total Result Minimum of all results: Kappa ≥ 0.90: ☐ capable 0.70 ≤ Kappa < 0.90: ☑ conditionally capable
Comment: none
Date: 02/29/2009 Department: W025 Name: J. Q. Public Signa…

Procedure 6&7 – Stability or repetition?

- There are no defined requirements for stability checks for test process capability
- An np- or p-chart as used in SPC would be an obvious possibility
- However, these charts typically use sample sizes $n \geq 50$
- So stability monitoring would essentially be an ongoing repetition of procedure 7
- Some typical criteria for a repeat test:
  - When commissioning a new, overhauled or repaired test equipment; after maintenance work
  - After technical changes to an test equipment
  - After additions or significant changes to reference standards
  - After a change of test process conditions or appraisers
  - See also criteria for repeating measurement process capability studies

Non-capable measurement or test processes



Observe sequence :

- ➔ **Optimize measurement processes**
  - ➔ **Measuring equipment, standards**
  - ➔ **Measurement procedure, strategy**
  - ➔ **Environmental conditions**
  - ➔ **Object of measurement**
  - ➔ **Appraisers, instructions**
- ➔ **Purchase more precise measuring system**
- ➔ **Look at characteristic, tolerance, and measurement process**

Many thanks for your interest and cooperation

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T&T Quality Engineering RO SRL