



QM-ST-40 Capability of Measurement and Test Processes

C/QMM, 05/01/2026

Webinar general information/rules



Before we start ...

Microphone



Please keep it **muted** to avoid background noise during the session.

Camera



Turning it on helps make the session more engaging and less monotonous.

Chat



Feel free to drop your **questions or comments** there anytime.

Timing



We'll keep track to make sure **we finish on schedule**.

Focus



Let's stay present and **avoid multitasking** during the session.

Feedback



Don't hesitate to share it at the end, it really **helps us improve!**

Classroom general information/rules



Before we start ...

Participation

Please **raise your hand** if you want to ask a question or share a comment.

Respect

listen respectfully without interrupting.

Engagement

Join discussions and activities.

Timing

We'll keep track to make sure **we finish on schedule**.

Focus

Let's stay present and **avoid multitasking** during the session.

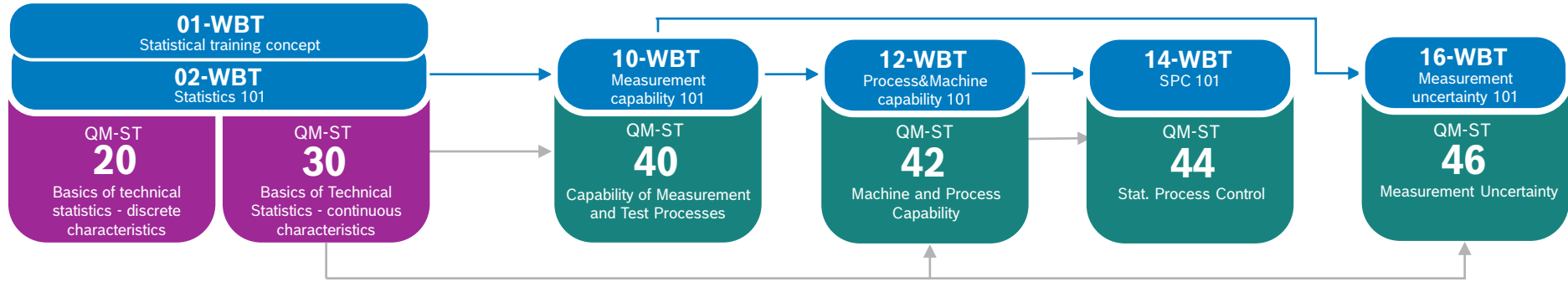
Feedback

Don't hesitate to share it at the end, it really **helps us improve!**

Technical statistics trainings: concept from 2026 onwards



Introductory WBTs



Base statistics

Method expert



Tooling user

Tooling expert and Keyuser

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Introduction



Introduction

 Definitions and requirements from standards

 MSA methods acc to Bosch booklet 10

 Assessment of non-capable processes and approval decision

 Causes of non-capable measurement systems

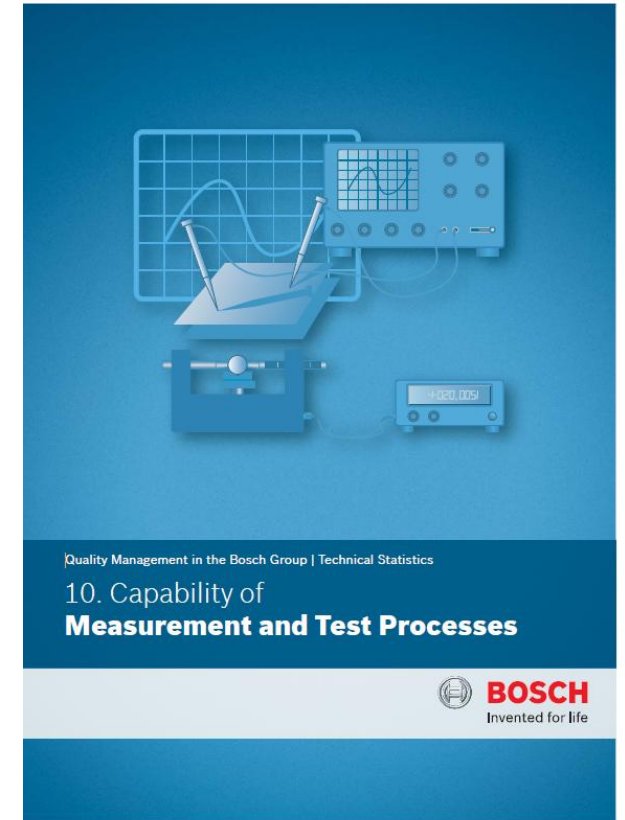
Introduction

Learning objectives



After the training you will be able:

- To select and use appropriate procedures to verify the capability of measurement and test processes.
- To know all the procedures described in Bosch Booklet 10 and know how to interpret and evaluate their results
- To know the procedures' 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



02

Definitions and requirements from standards



 Introduction

 **Definitions and requirements from standards**

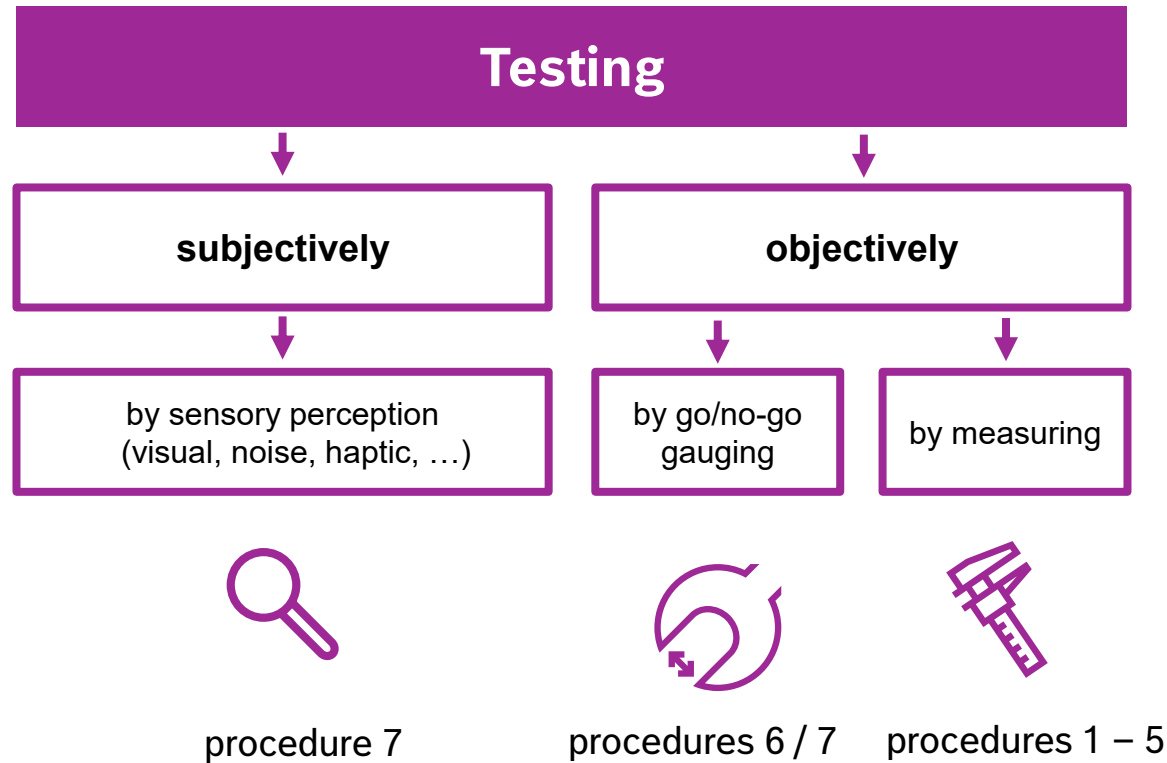
 MSA methods acc to Bosch booklet 10

 Assessment of non-capable processes and approval decision

 Causes of non-capable measurement systems

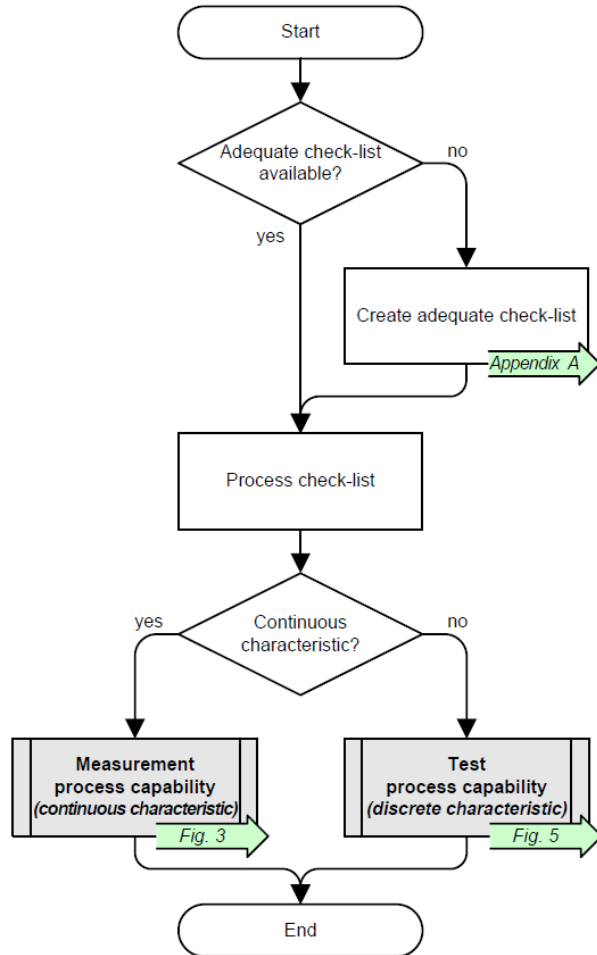
Definitions and requirements from standards

Test and measurement



Definitions and requirements from standards

Test and measurement



Even if you can test by measuring, Booklet 10 indicates:

- Measurement process capability for **continuous** characteristics
- Test process capability for **discrete** characteristics

Quote from Booklet 10, Chapter 5:

- **Note:** The analysis using discrete or discretized characteristics is generally not recommended, since meeting up-to-date requirements for error rates requires sample sizes which are economically not justifiable. The verification of capability by means of continuous characteristics using procedures 1 - 5 should always be preferred.



Definitions and requirements from standards

“Measurement process” and “measurement system”

- AIAG Core Tool MSA 4th Edition

Terminology

Chapter I – Section A
Introduction, Purpose and Terminology

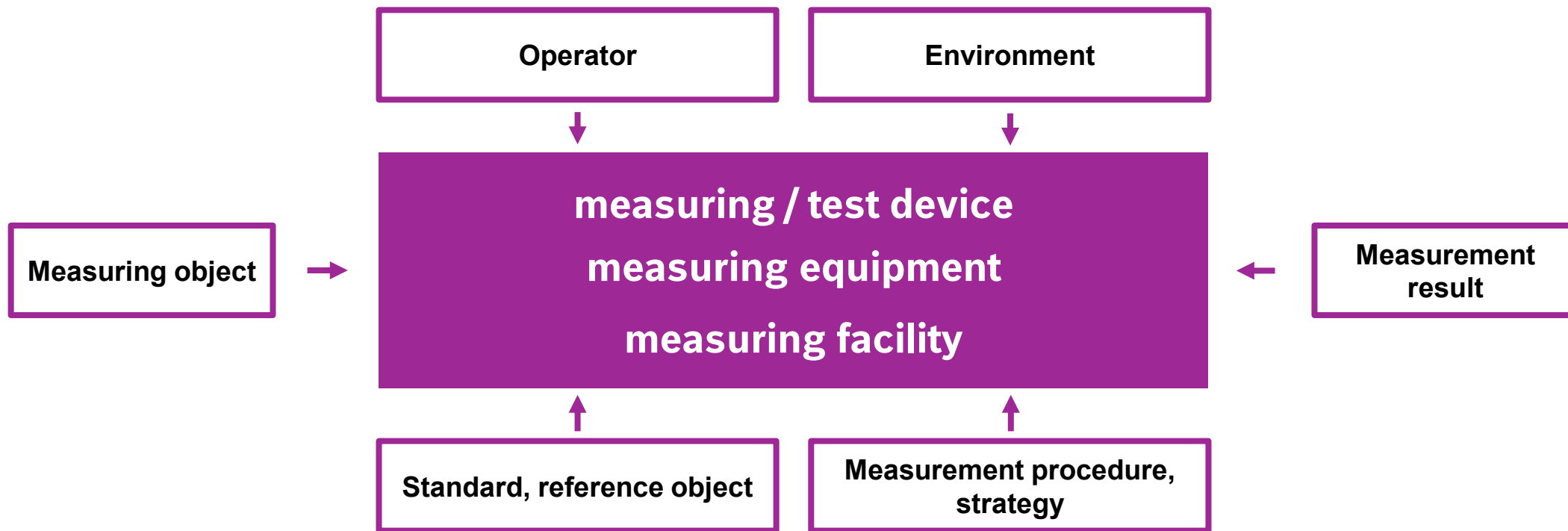
- **Measurement System** is the collection of instruments or gages, standards, operations, methods, fixtures, software, personnel, environment and assumptions used to quantify a unit of measure or fix assessment to the feature characteristic being measured; the complete process used to obtain measurements.

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.



Definitions and requirements from standards

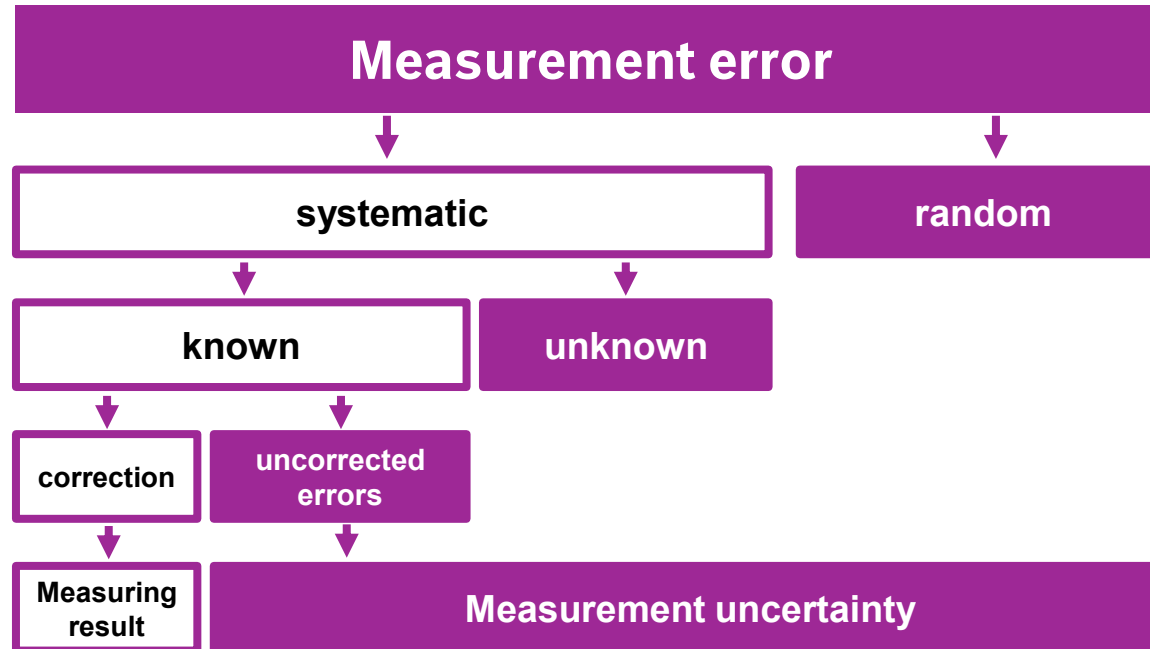
“Measurement process” and “measurement system”





Definitions and requirements from standards

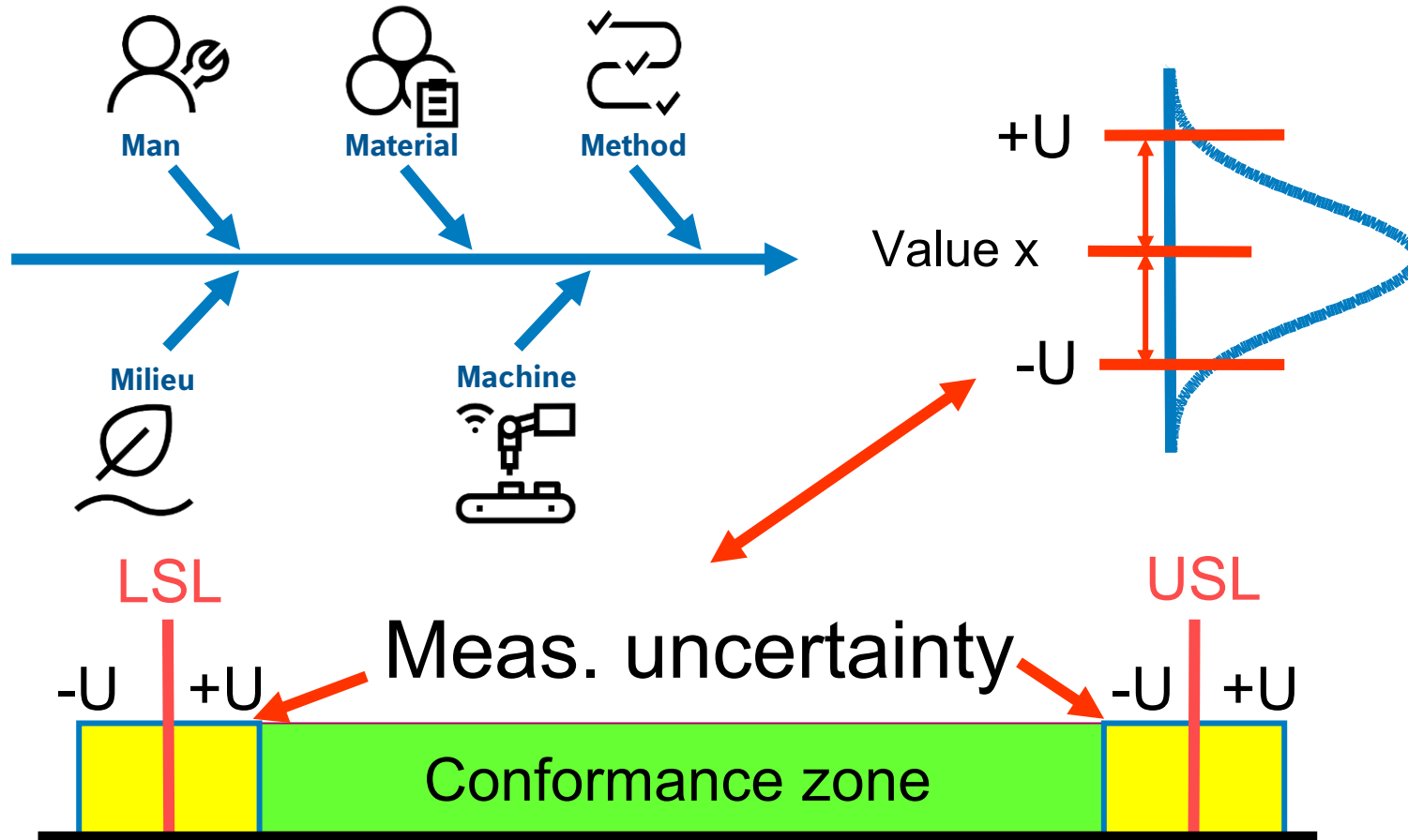
Classification of measurement errors





Definitions and requirements from standards

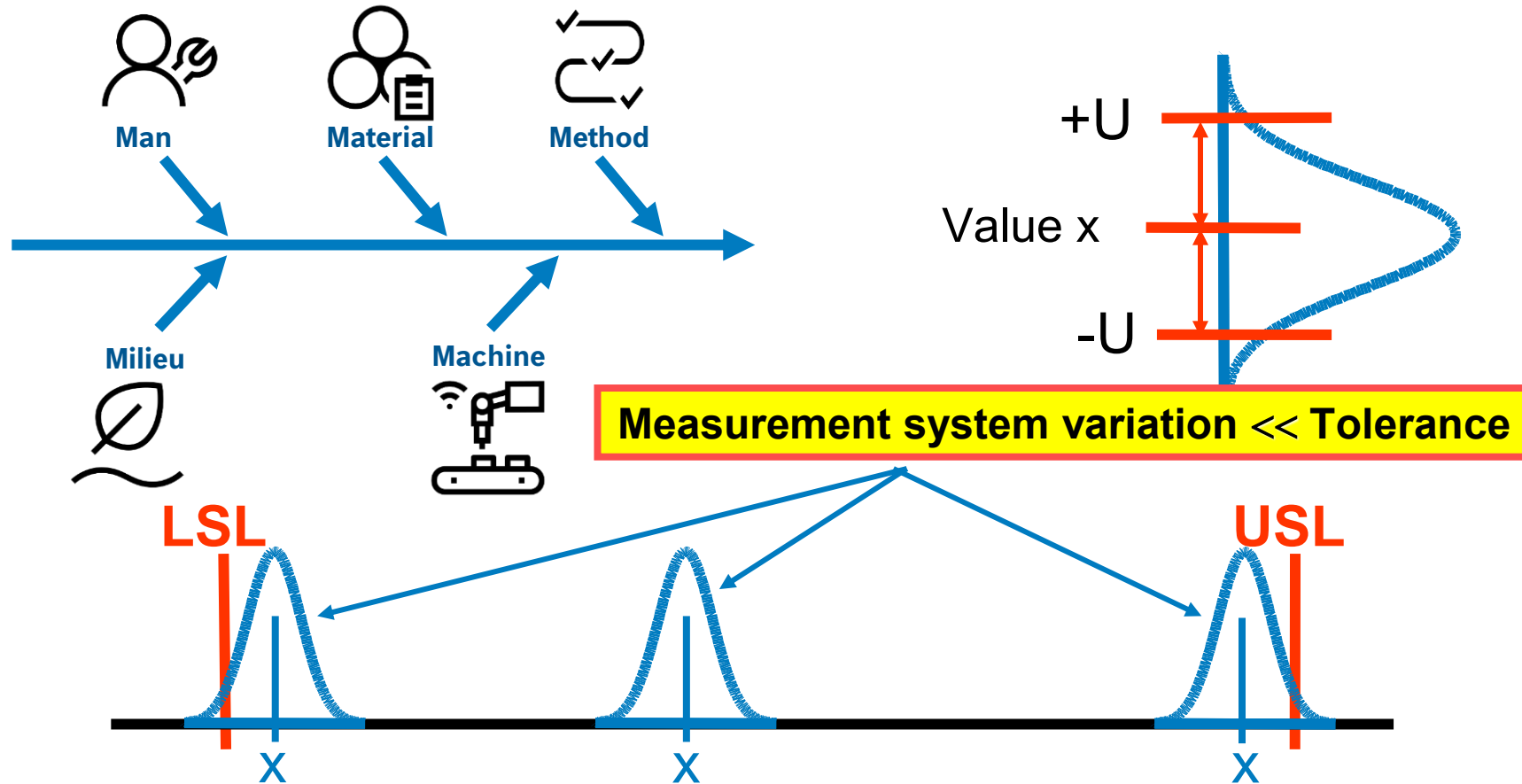
Taking measurement errors into account





Definitions and requirements from standards

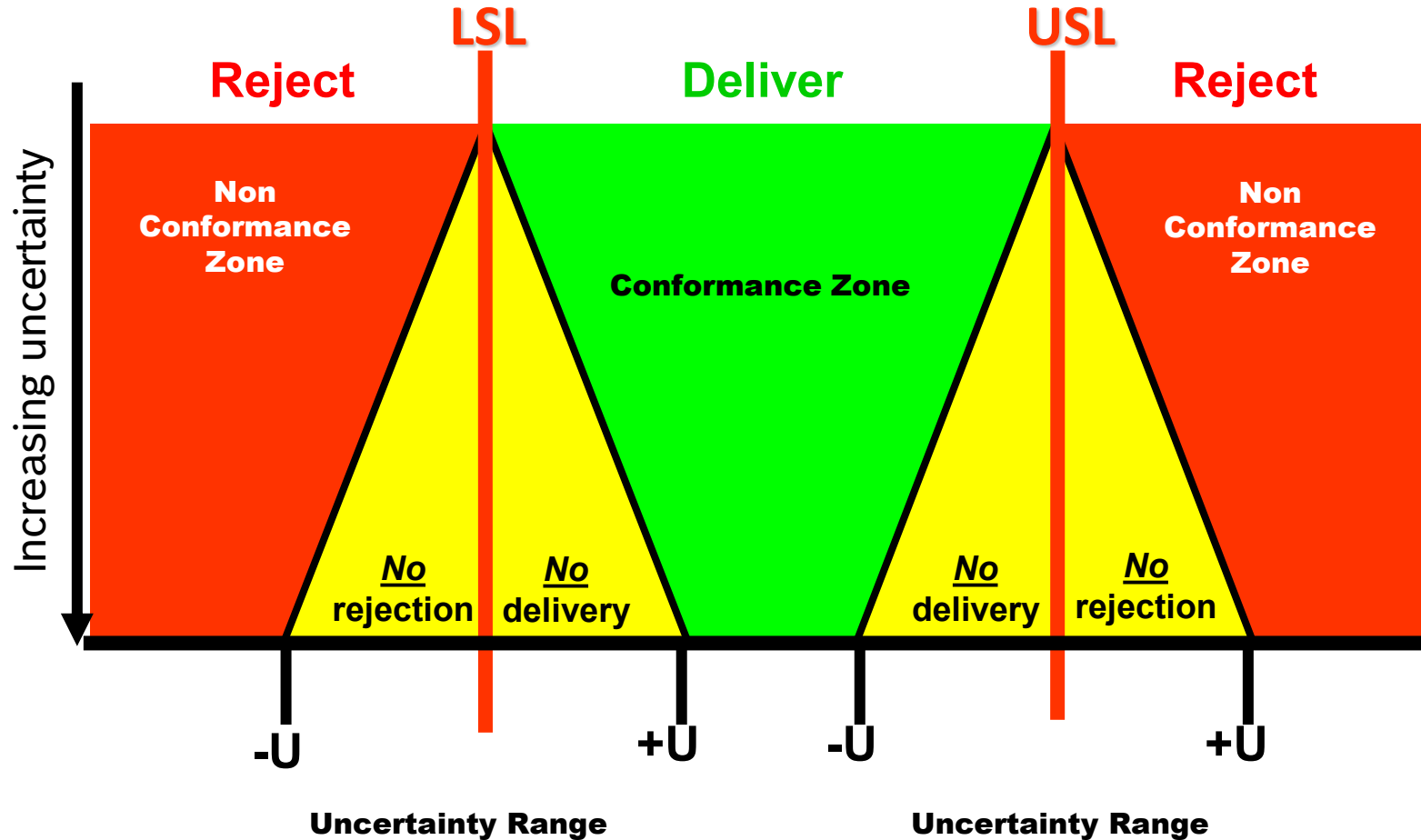
Taking measurement errors into account





Definitions and requirements from standards

ISO 14253 requirement



Definitions and requirements from standards

Statements from booklet 10, chapter 2



- The verification of capability has to be provided by means of measurements and tests at the place of operation of the measuring or test systems and statistical analyses of the results.
- It is only reasonable for measuring and test systems that conduct a sufficiently large number of similar recurring measurements and tests (e. g. in the production flow) and it is valid for the examined characteristic only.
- If measurements and tests of different characteristics are done with the same measuring or test system, an individual verification of capability is required for each characteristic.
- In case of frequently changing measurement tasks (e. g. in development and test departments), measurement uncertainties should be determined rather than capabilities.
- If conformity statements according to [ISO 14253] are required, measurement uncertainties have to be determined categorically instead of or in addition to capabilities.
- If procedures contained in this issue of Booklet 10 cannot be applied for justified reasons, other procedures according to [AIAG MSA] have to be examined for their applicability and used.



Definitions and requirements from standards

Impact of measurement process variation

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

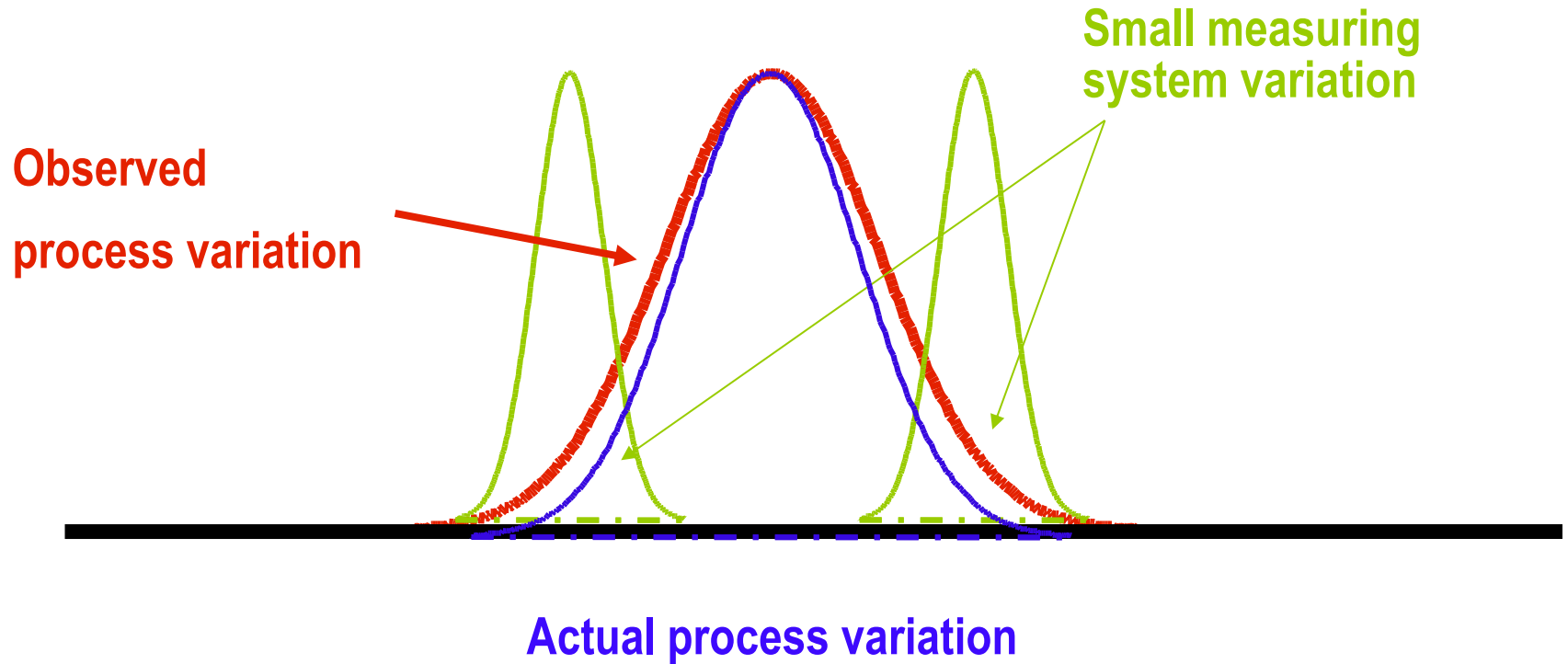


Impact on process capability!



Definitions and requirements from standards

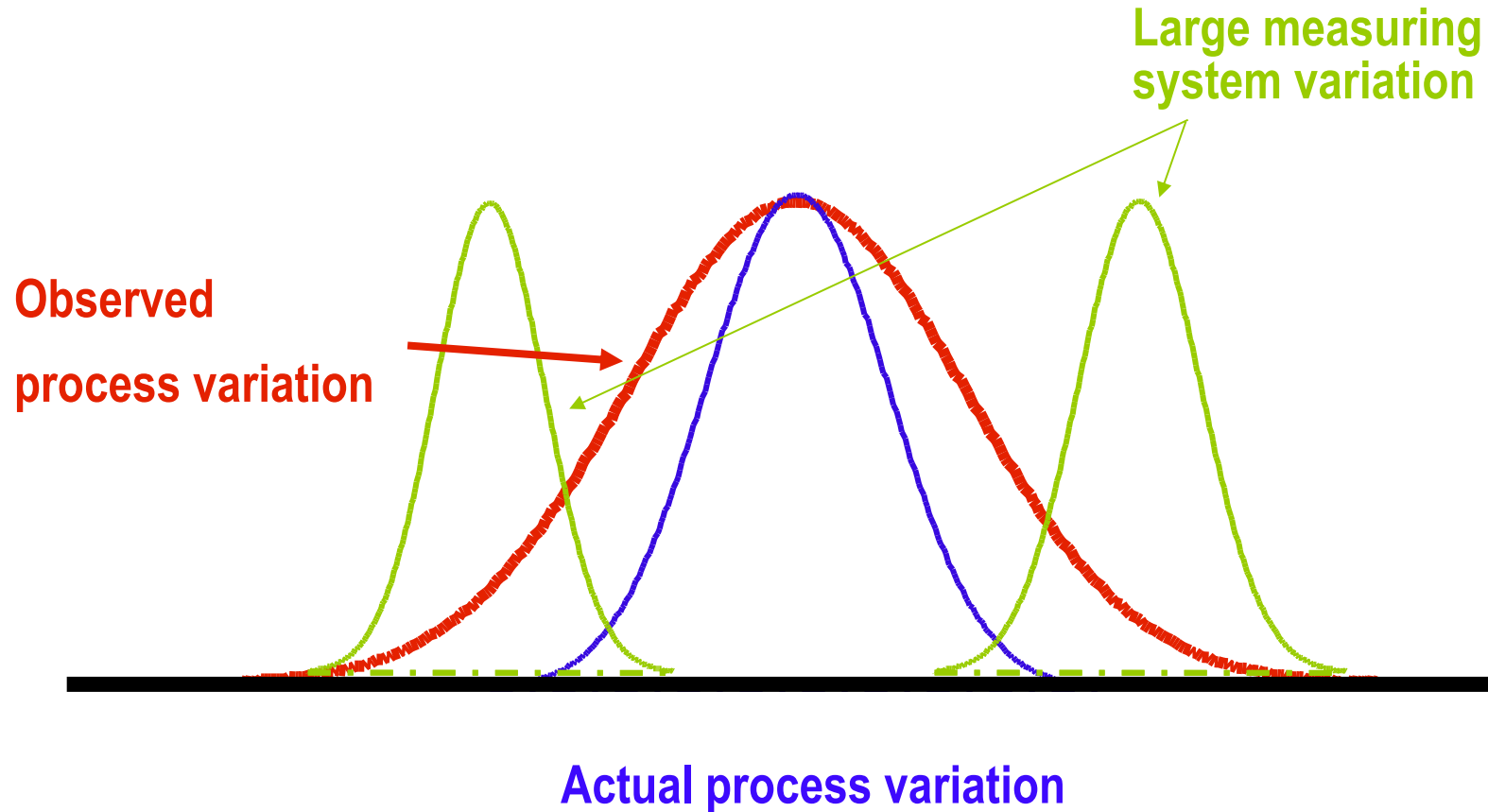
Impact of measurement process variation





Definitions and requirements from standards

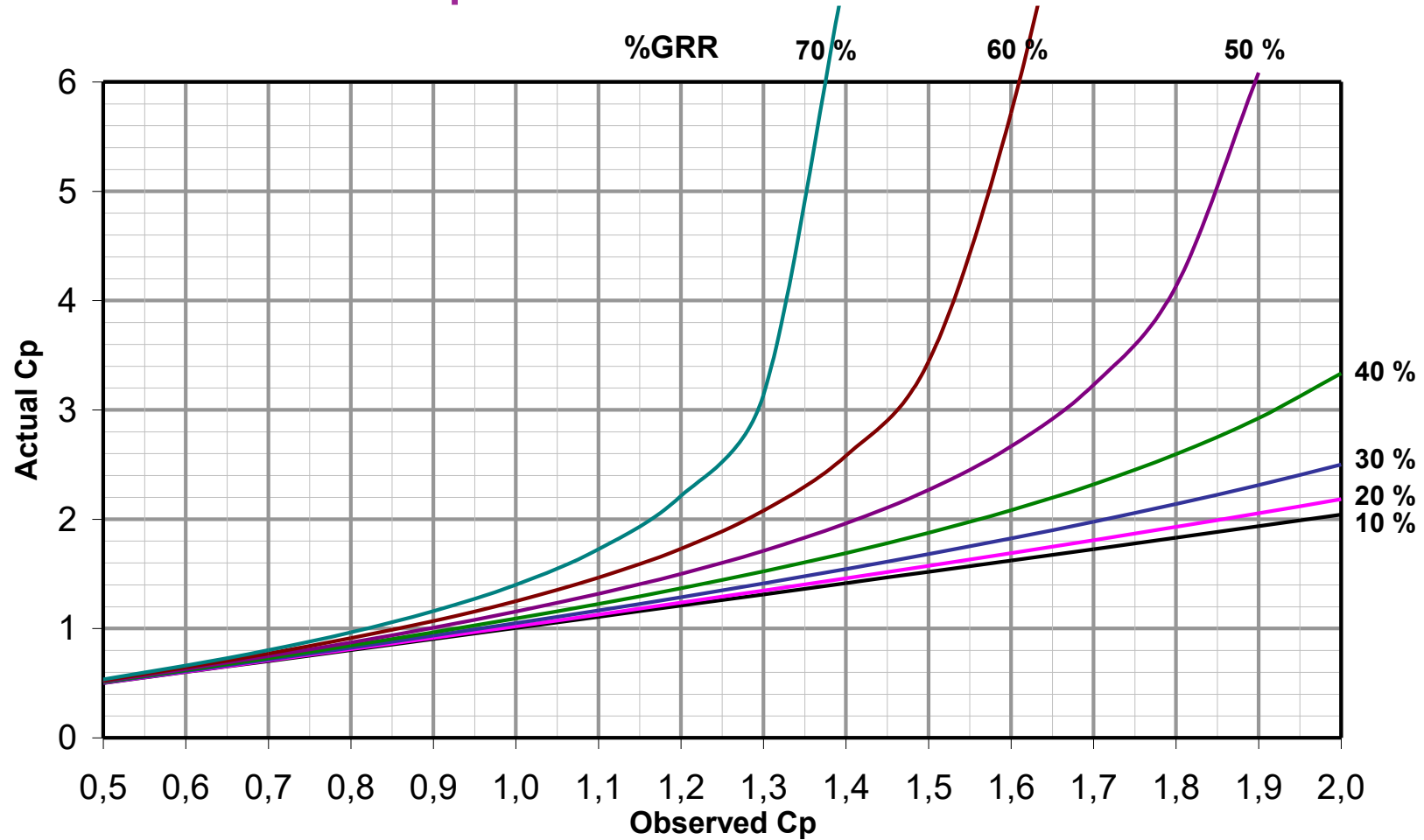
Impact of measurement process variation





Definitions and requirements from standards






Impact of measurement process variation



03

MSA methods acc to Bosch booklet 10

03

-  Introduction
-  Definitions and requirements from standards
-  **MSA methods acc to Bosch booklet 10**
-  Assessment of non-capable processes and approval decision
-  Causes of non-capable measurement systems



MSA methods acc to Bosch booklet 10

Methods according to Bosch booklet 10: overview

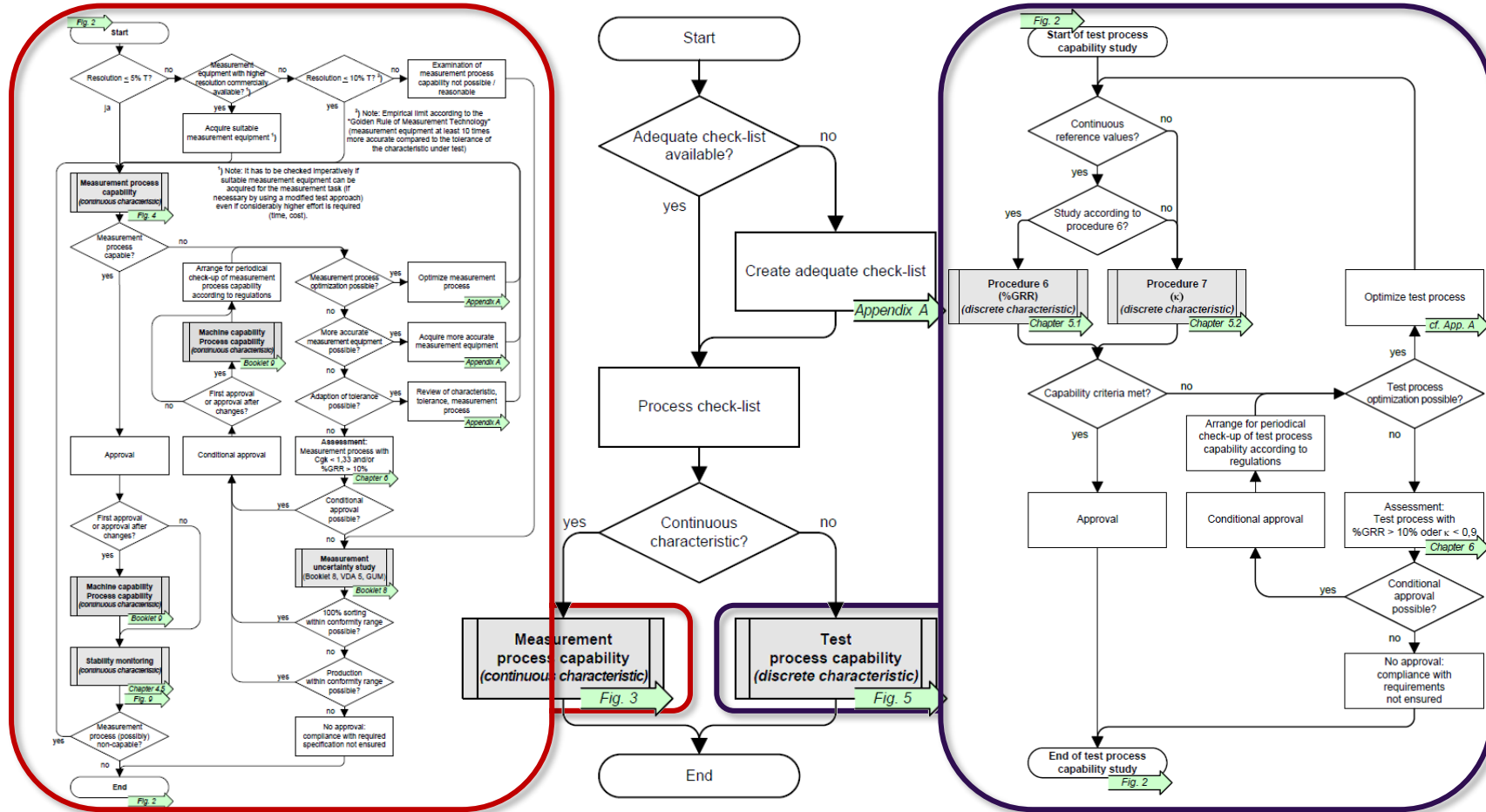
- Procedure 1 – Measurement of standard/reference - C_g / C_{gk}
 - Prerequisite for procedures 2 to 5
- Procedure 2 – Repeatability and reproducibility - %GRR
 - Influence of real parts and appraisers
- Procedure 3 – Appraiser-independent systems - %GRR
 - Replaces procedure 2 for appraiser-independent 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 procedures
for approval of variable
measuring systems*



MSA methods acc to Bosch booklet 10

Methods according to Bosch booklet 10: overview

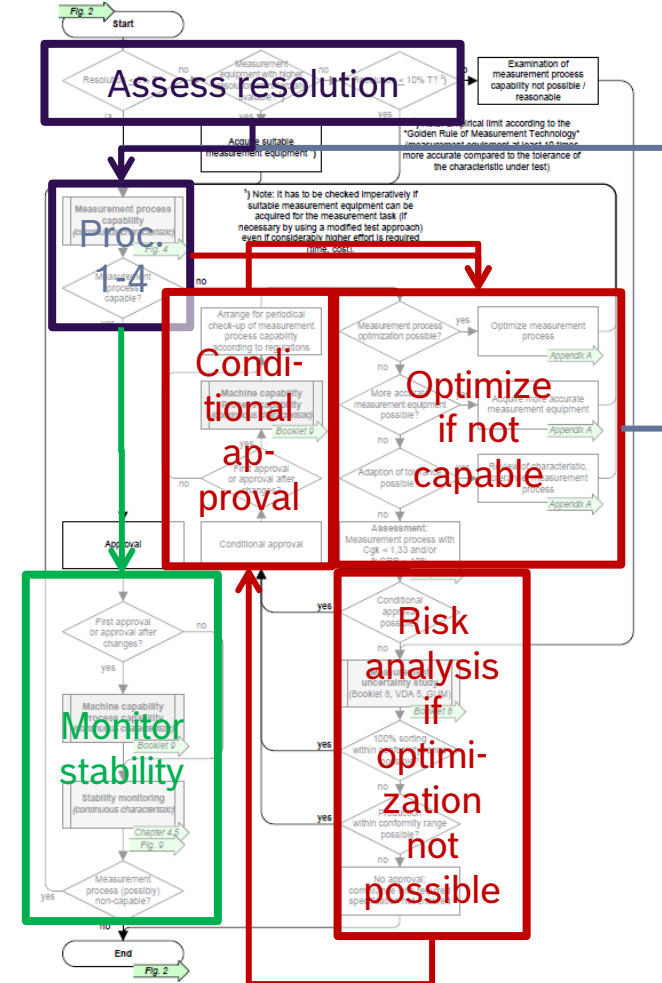




MSA methods acc to Bosch booklet 10

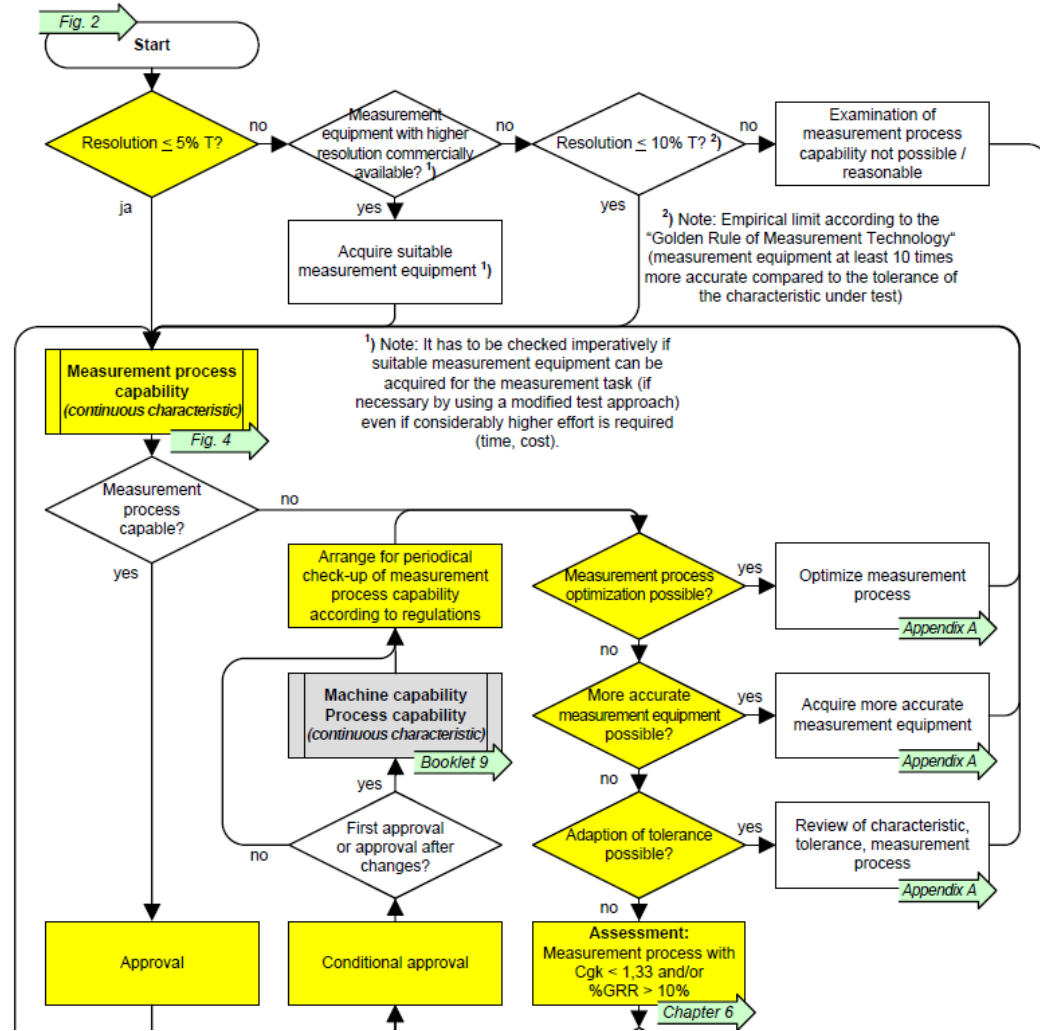
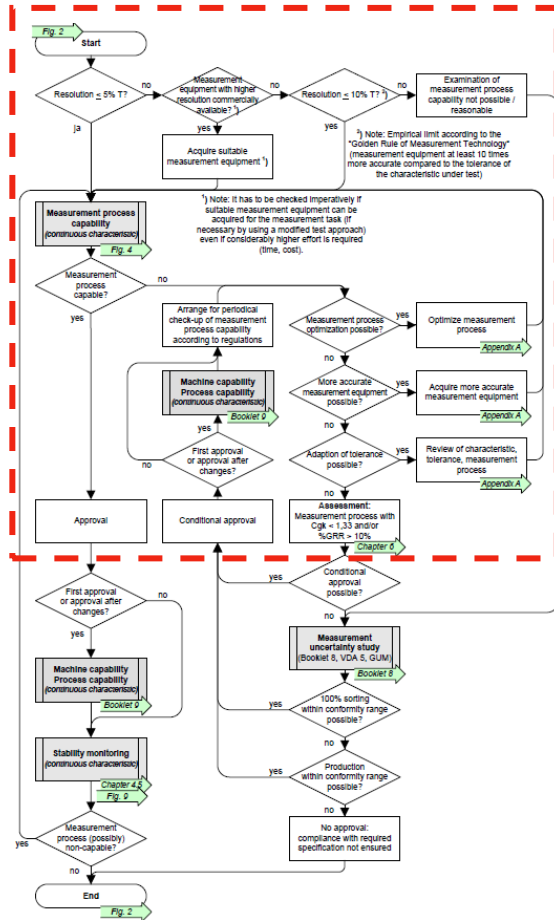
Flow chart: measurement process

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



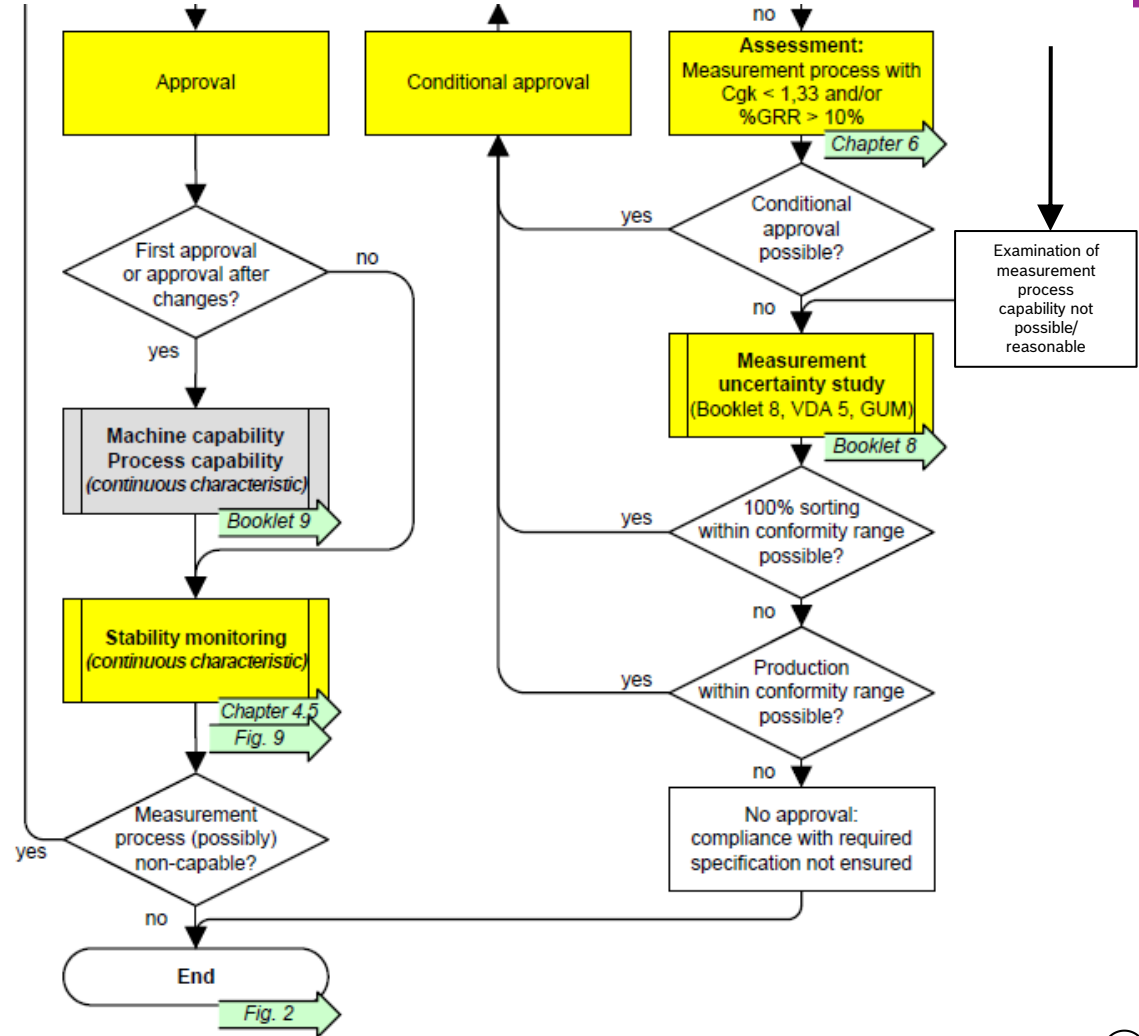
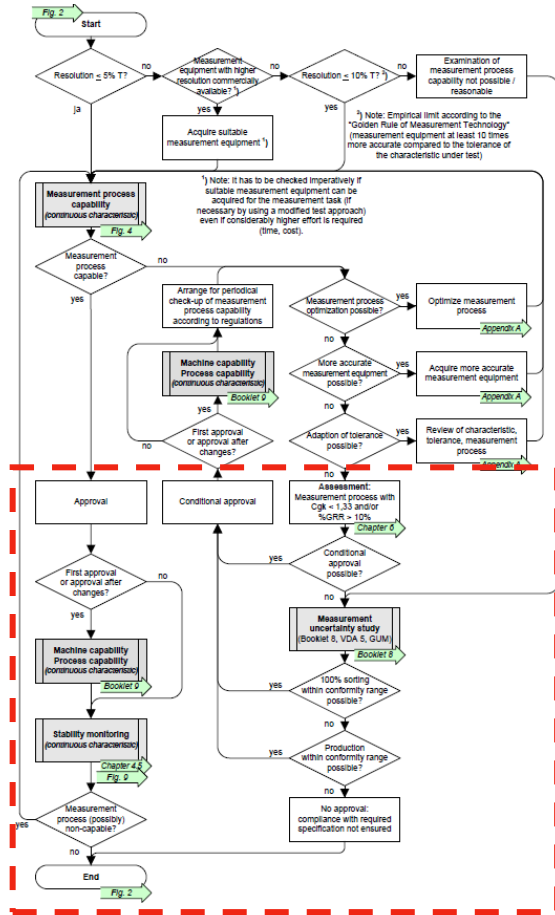
MSA methods acc to Bosch booklet 10

Flow charts



MSA methods acc to Bosch booklet 10

Flow charts





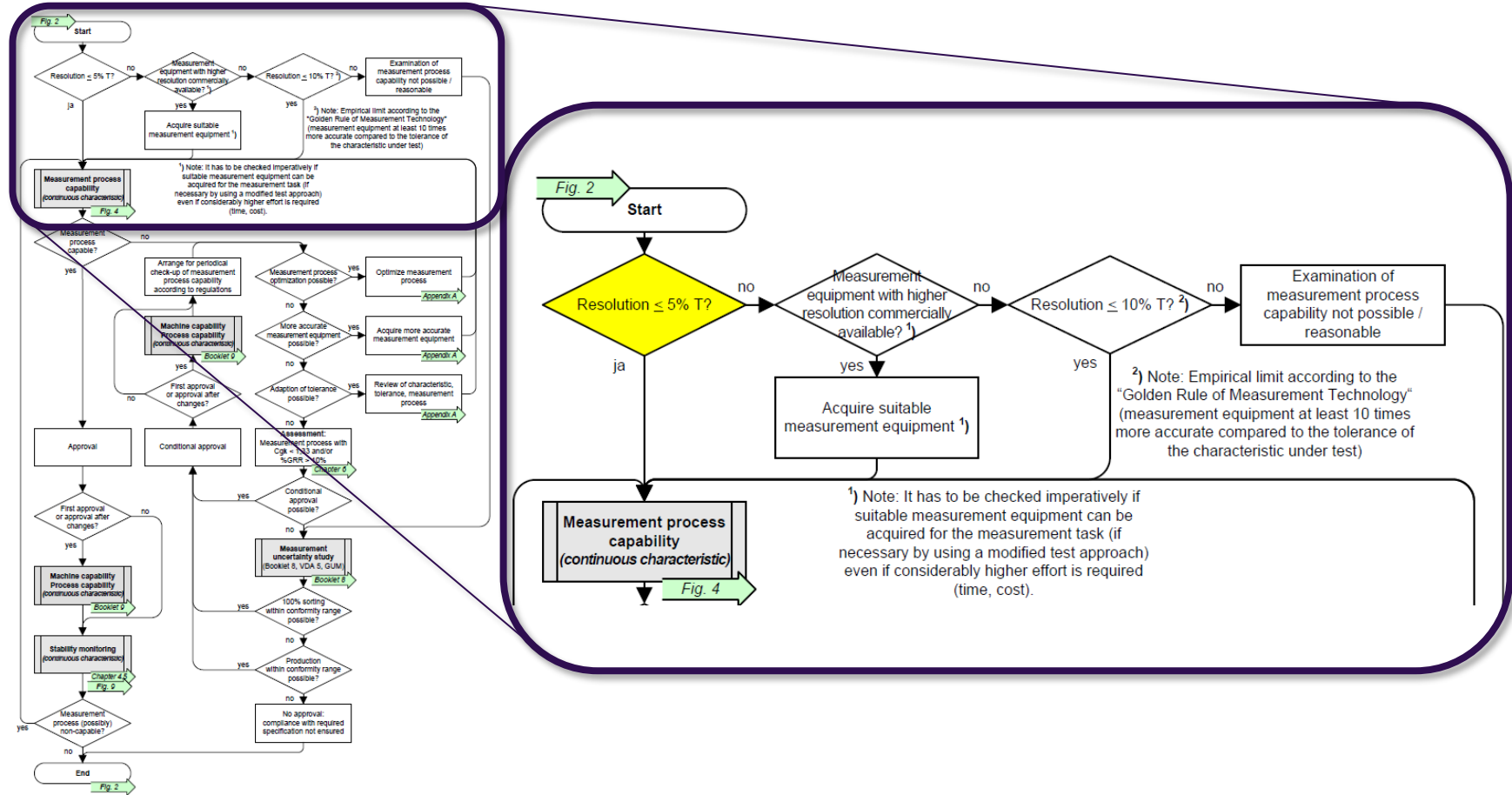
MSA methods acc to Bosch booklet 10

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

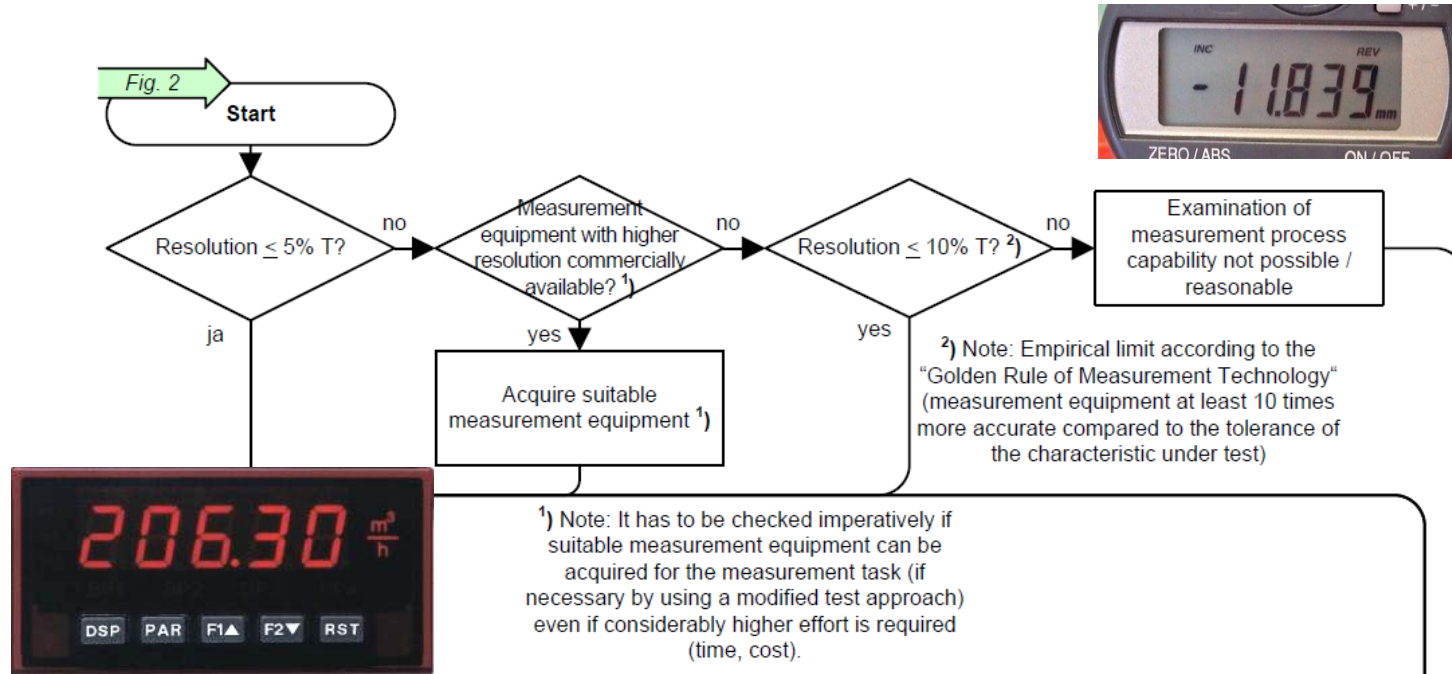
MSA methods acc to Bosch booklet 10

Flow chart



MSA methods acc to Bosch booklet 10

Resolution of a display

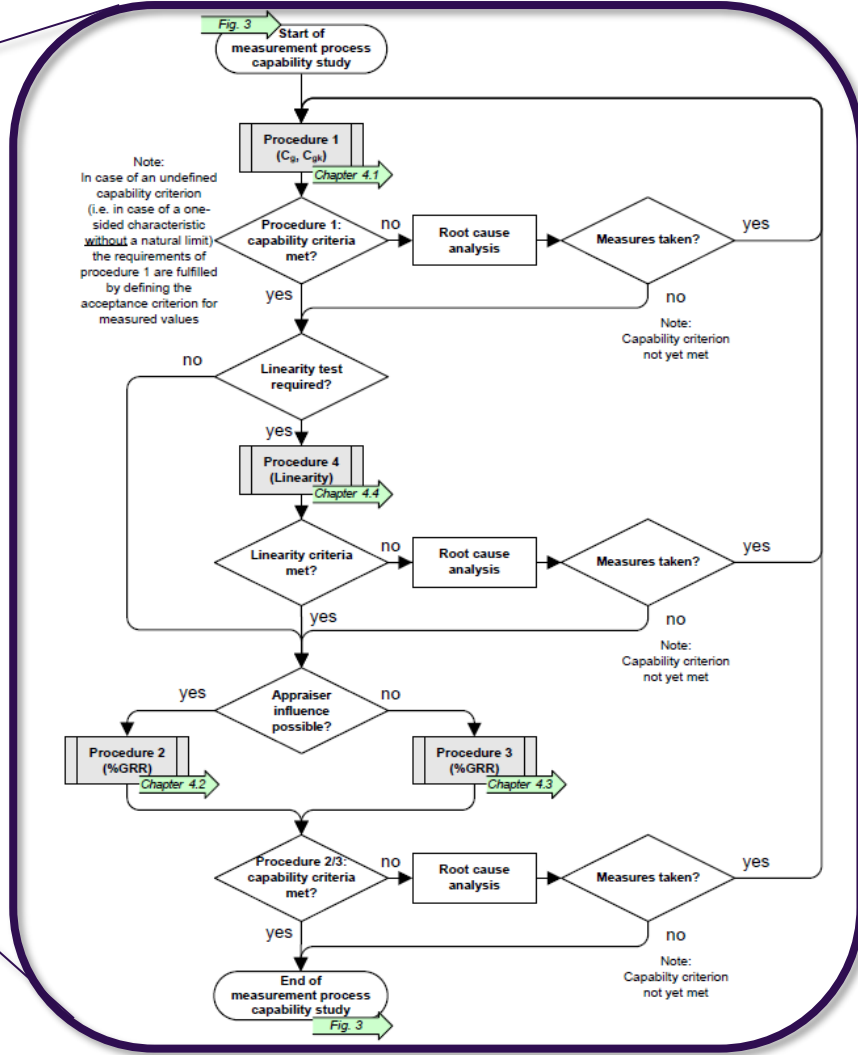
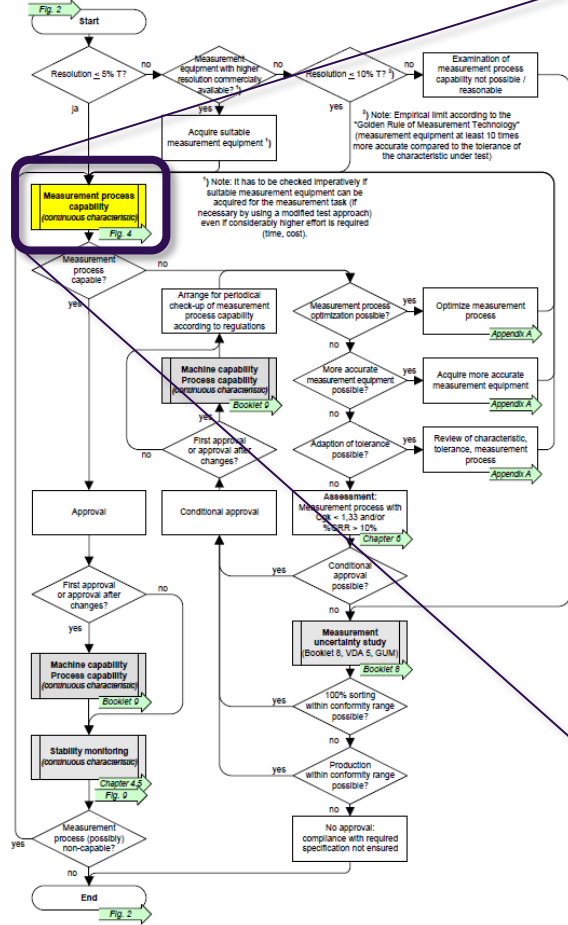


Resolution: the smallest change in a measured characteristic that causes a noticeable change in the relevant display [VIM, 4.14]

Resolution of a display: the smallest difference between indicated values that can be meaningfully distinguished [VIM, 4.15]

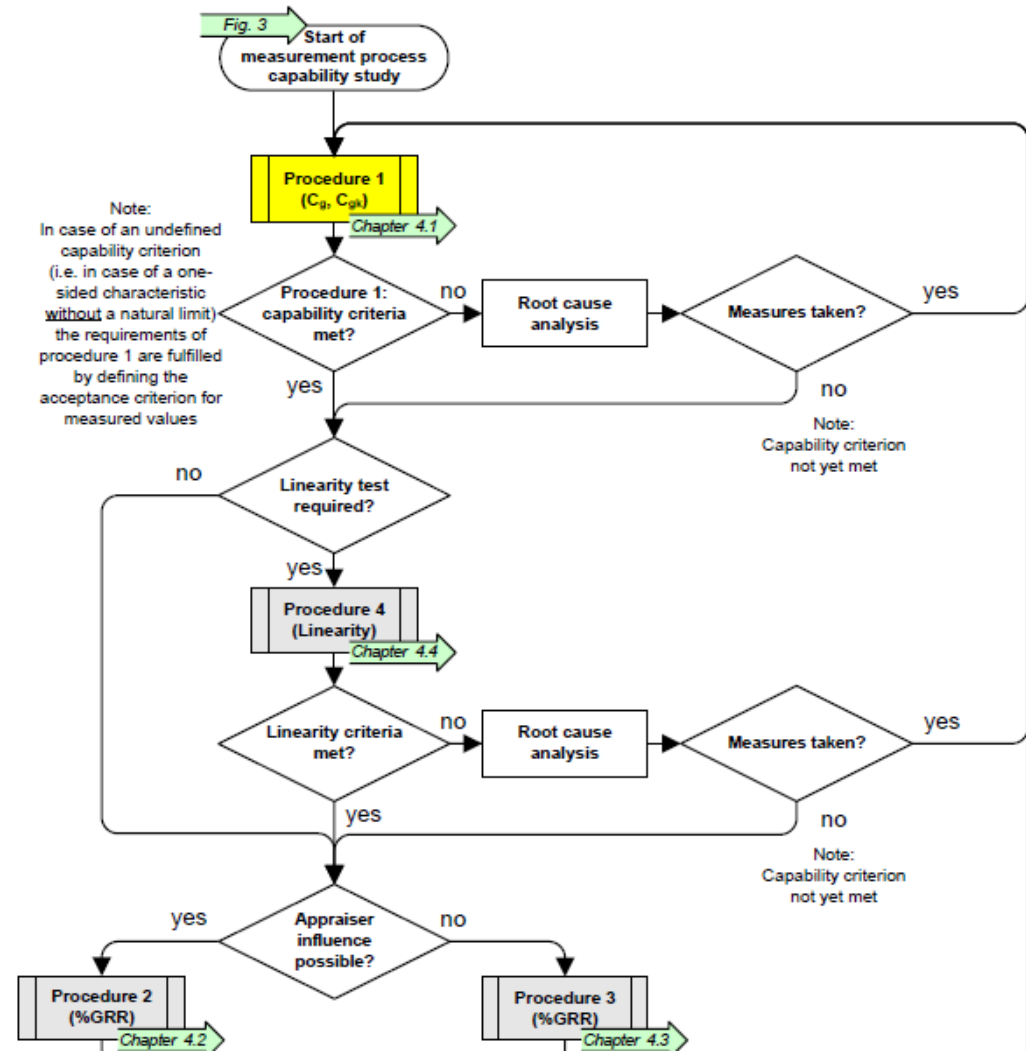
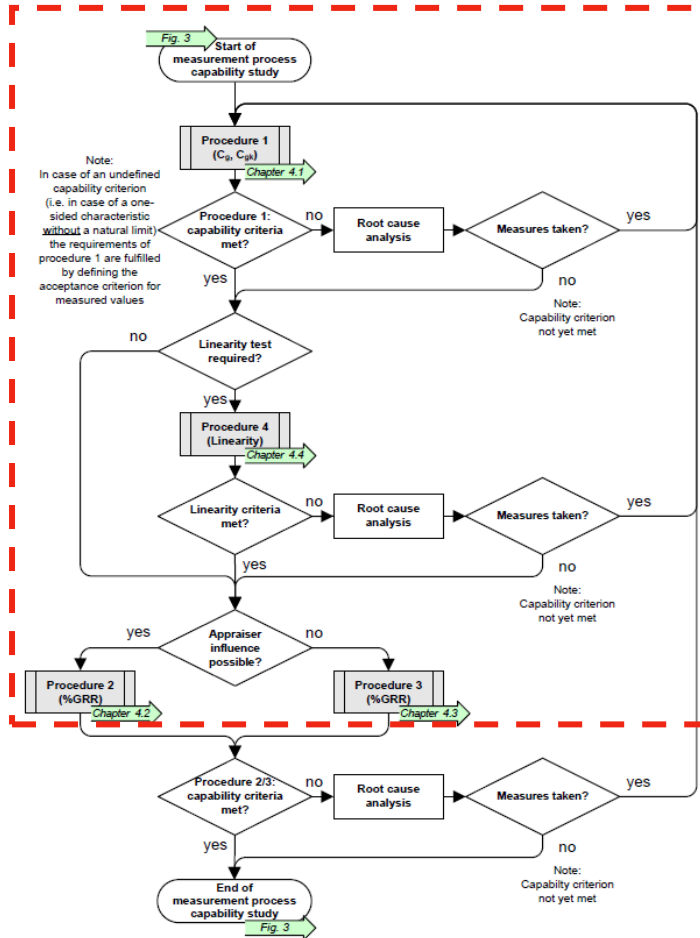
MSA methods acc to Bosch booklet 10

Flow chart



MSA methods acc to Bosch booklet 10

Flow charts





MSA methods acc to Bosch booklet 10

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

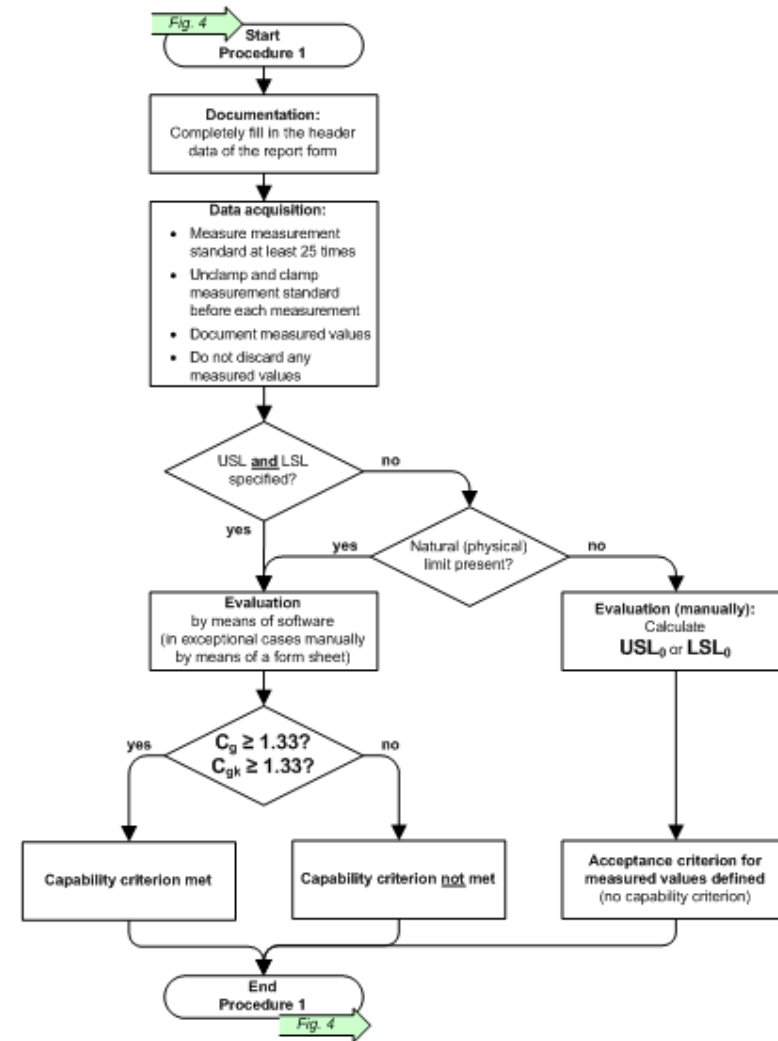
- The standard is measured 50 times (min. 25 times) under repeatability conditions



MSA methods acc to Bosch booklet 10

Procedure 1: process

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

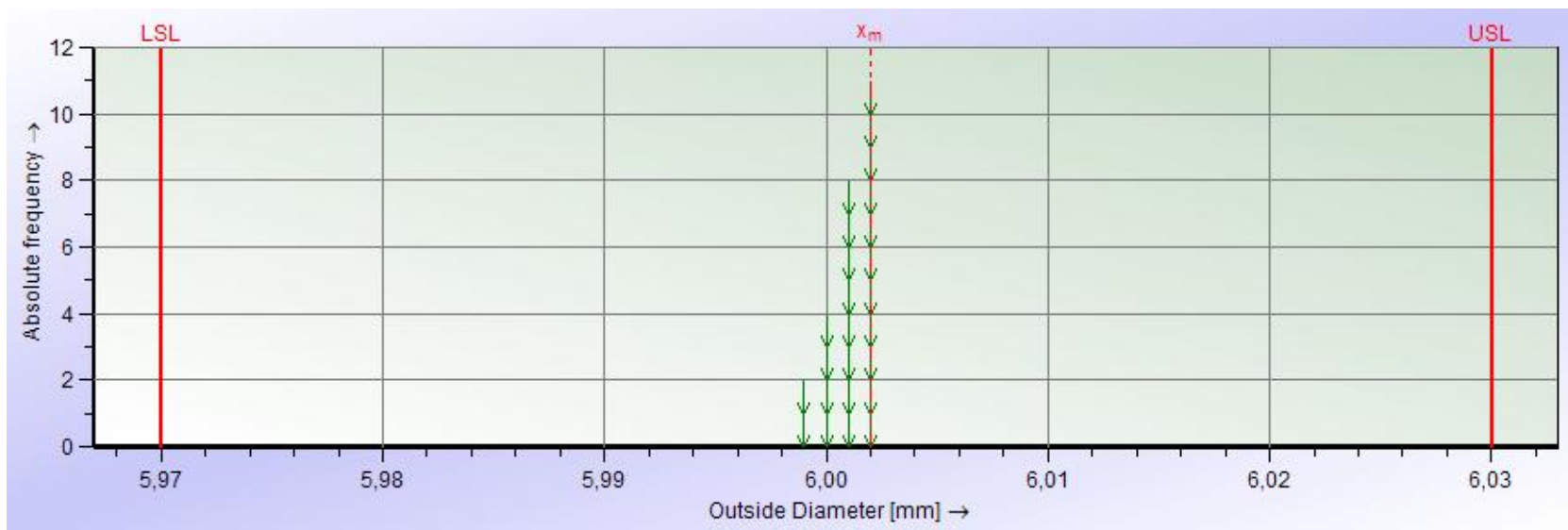




MSA methods acc to Bosch booklet 10

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)





MSA methods acc to Bosch booklet 10

Procedure 1: components of uncertainty

Bias

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

Spread

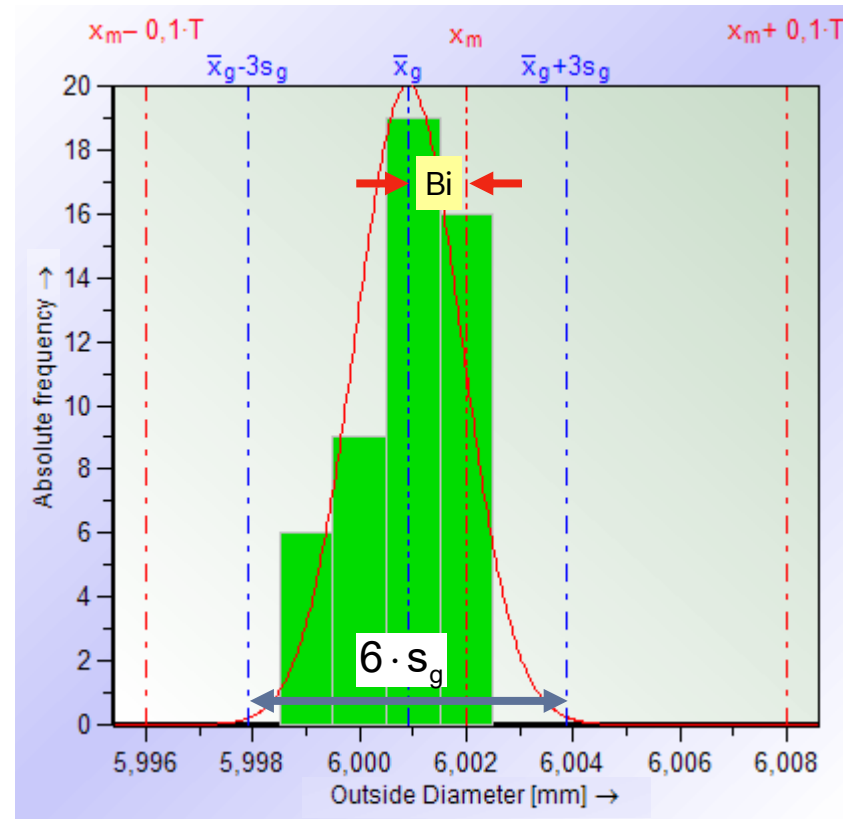
$$6 s_g$$

Remember:

✓ Mean

✓ Standard deviation

$$\bar{x}_g = \frac{\sum x_i}{n}$$
$$s_g = \sqrt{\frac{\sum (\bar{x} - x_i)^2}{n-1}}$$





MSA methods acc to Bosch booklet 10

Procedure 1: calculating the indices

Bias

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

Capability indices:

$$C_g = \frac{0.2 \cdot T}{6 \cdot s_g}$$

$$C_{gk} = \frac{0.1 \cdot T - |B_i|}{3 \cdot s_g}$$

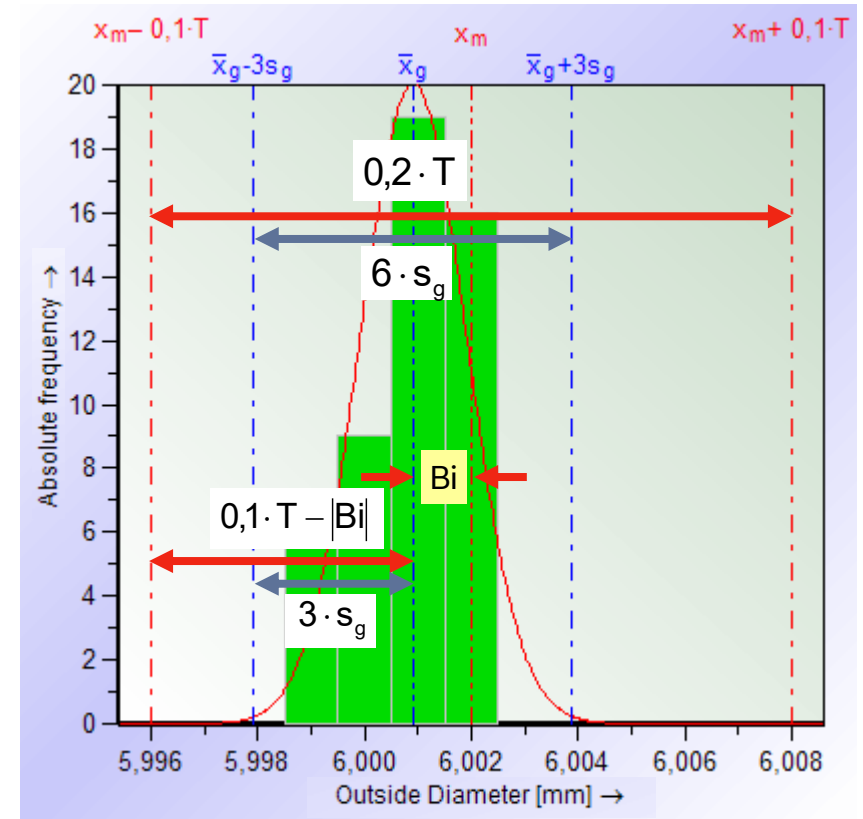
Remember:

✓ Mean

✓ Standard deviation

$$\bar{x}_g = \frac{1}{n} \cdot \sum x_i$$

$$s_g = \sqrt{\frac{1}{n-1} \cdot (x_i - \bar{x})^2}$$



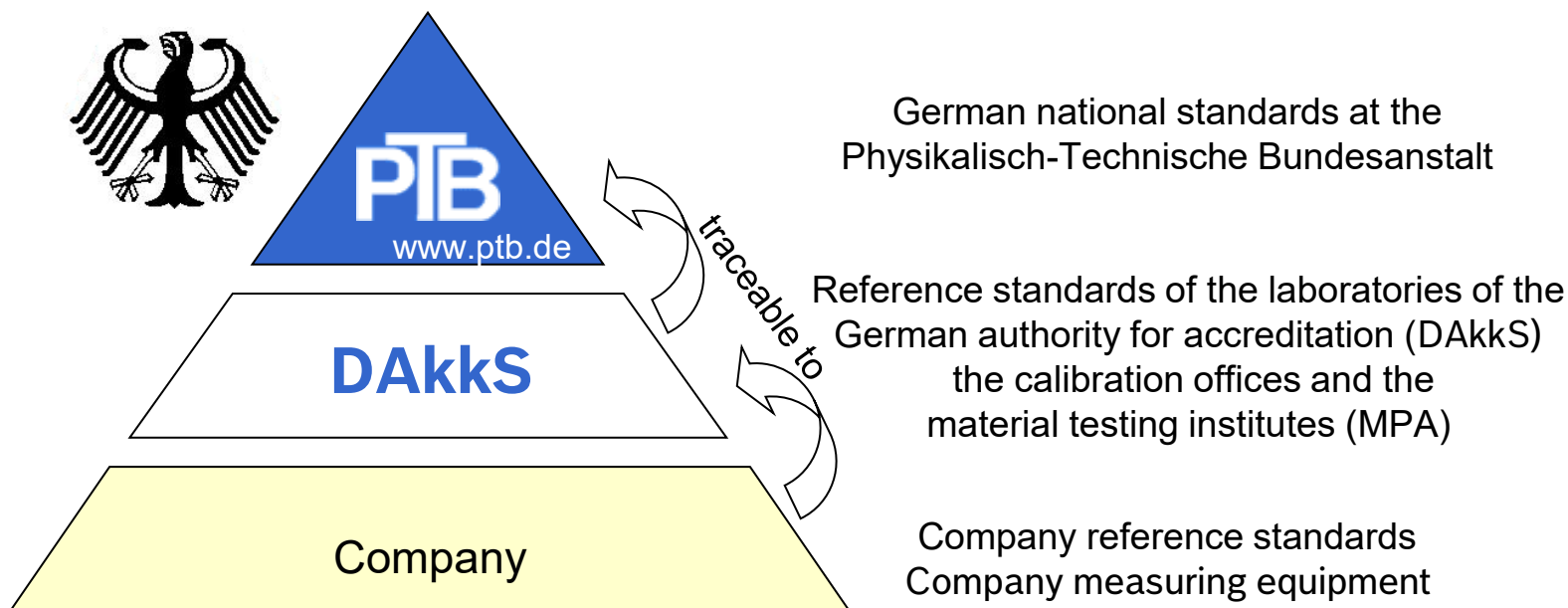


MSA methods acc to Bosch booklet 10

Requirements for the measurement standard

- Definition: 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.





MSA methods acc to Bosch booklet 10

Requirements for the measurement 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 $U_{cal} < 0.01 * T = 1\% T$
 - Minimum requirement $U_{cal} < 0.1 * T = 10\% T$
- If a corresponding object is not available, Procedure 1 cannot be performed, and a suitable alternative method has to be found



MSA methods acc to Bosch booklet 10

Procedure 1: assessment with a standard

Drawing Values			Collected Values			Statistics		
$x_m + 0.1 * T$	=	6.008	$x_{max\ g}$	=	6.002	$\bar{x}_g + 3 * s_g$	=	6.00388
x_m	=	6.002	$ B_i $	=	0,001100	\bar{x}_g	=	6.00090
$x_m - 0.1 * T$	=	5.996	$x_{min\ g}$	=	5.999	$\bar{x}_g + 3 * s_g$	=	5.99792
$0.2 * T$	=	0.012	R_g	=	0.003	$6 s_g$	=	0.00597
T	=	0.060	n_{ges}	=	50	s_g	=	0.00099488
Einheit	=	mm						

Test for Bias

Test result: significant ($\alpha \leq 0.1 \%$)

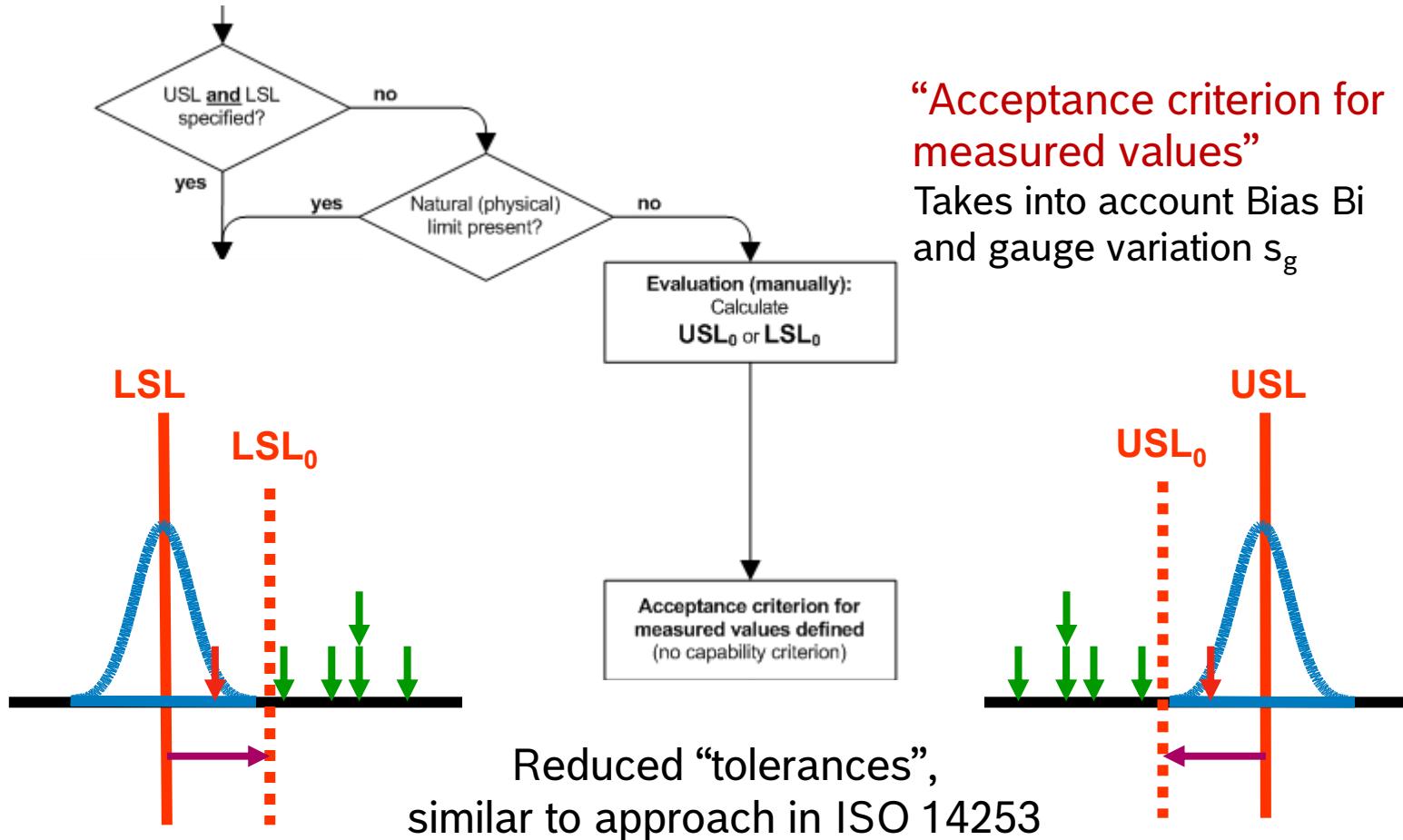
			Minimum reference for capable meas. system		
$C_g = 1.61 \leq 2.01 \leq 2.41$			$T_{min}(C_g)$	=	0.039701
$C_{gk} = 1.30 \leq 1.64 \leq 1.98$			$T_{min}(C_{gk})$	=	0.050696
Resolution	$\%RE = 1.67 \%$		$T_{min}(RE)$	=	0.020000
Measurement system capable (RE, C_g , C_{gk})					

Bosch 2018 — Procedure 1



MSA methods acc to Bosch booklet 10

Procedure 1: characteristics limited to only one side

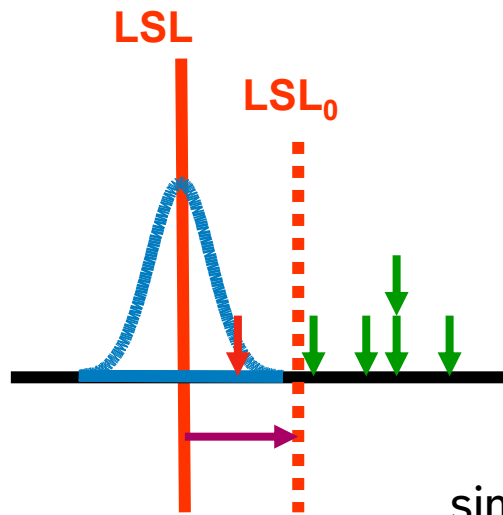




MSA methods acc to Bosch booklet 10

Procedure 1: characteristics limited to only one side

- 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 $\pm 10\%$ of the specification limit
- Bias B_i must enter the calculation with correct sign (!)
- 4 sg for $C_g / C_{gk} \geq 1.33$; 5 sg for $C_g / C_{gk} \geq 1.67$; 6 sg for $C_g / C_{gk} \geq 2.0$



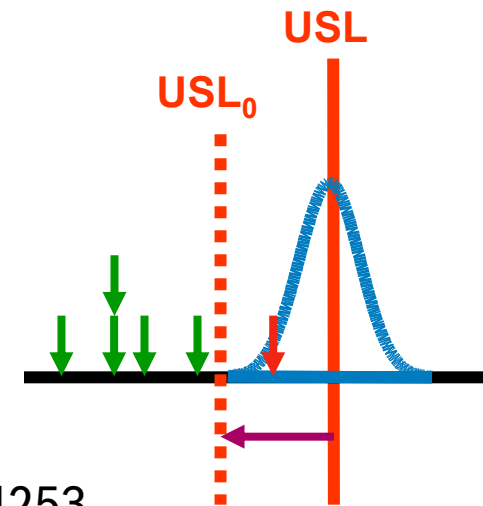
$$LSL_0 = LSL + B_i + 4s_g$$

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

where

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

Reduced “tolerances”,
similar to approach in ISO 14253





MSA methods acc to Bosch booklet 10

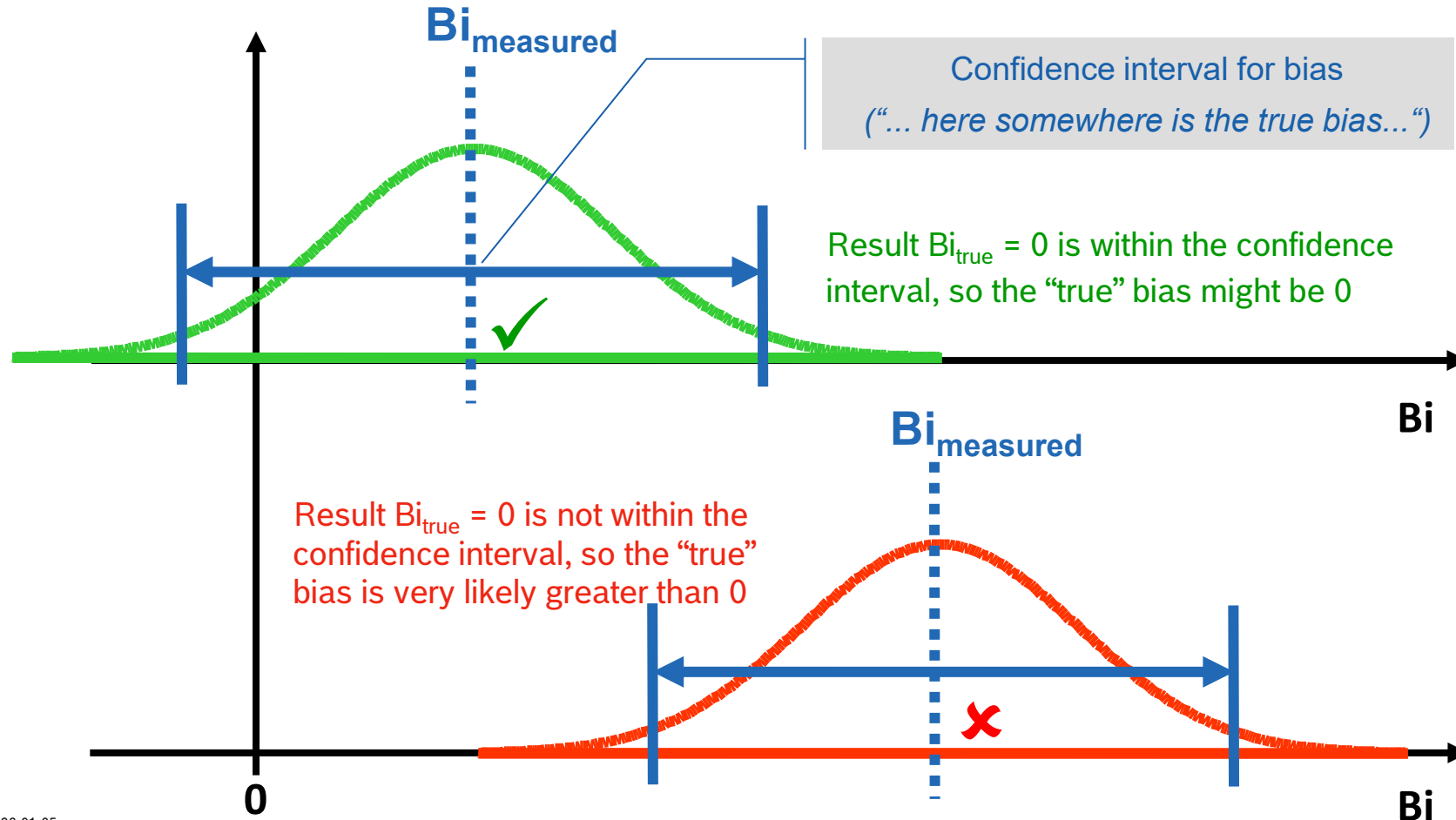
Alternative method according to AIAG MSA

- AIAG MSA does not contain the procedure 1. Instead, it recommends testing systematic measurement errors $B_i = \bar{x} - x_m$ for significance (test for significant bias)
- Approach of the test for significant bias:
 - The bias in a procedure 1 is calculated 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



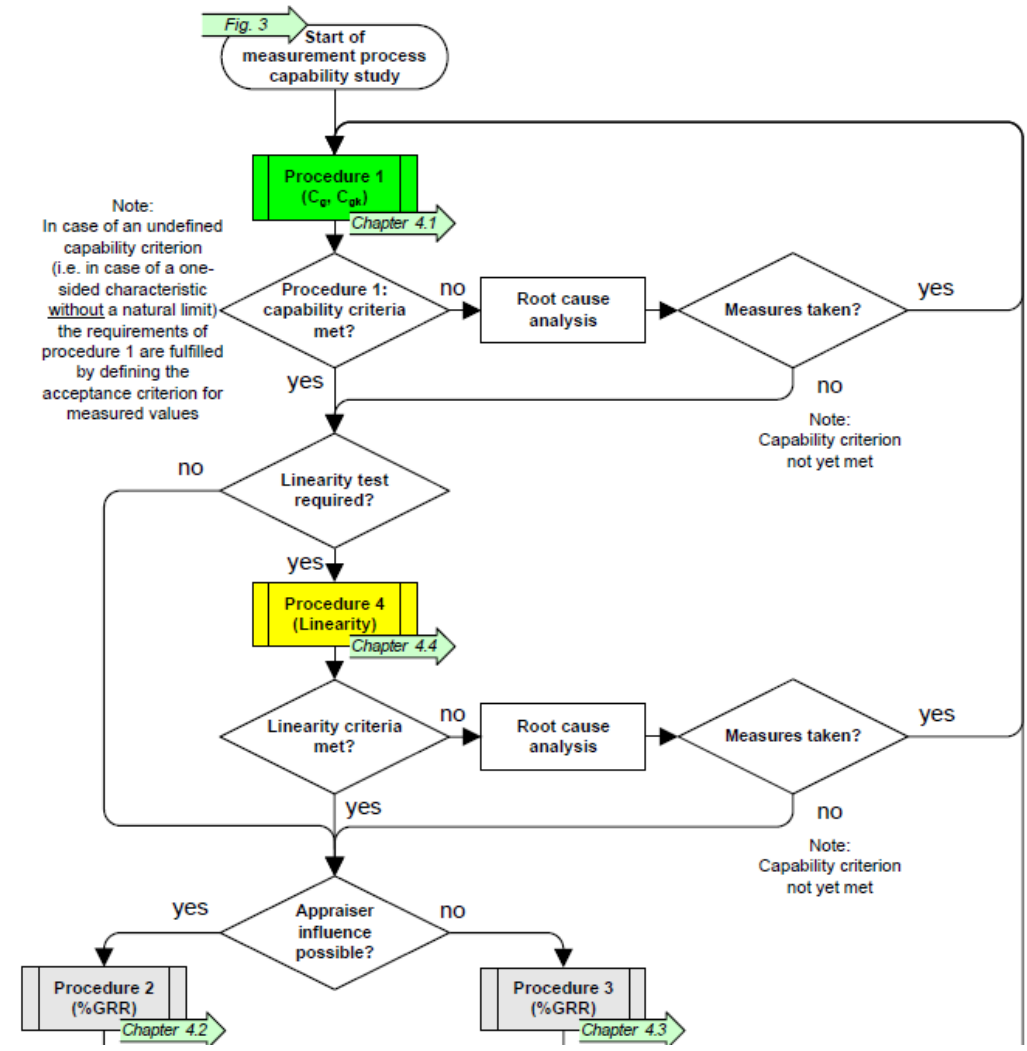
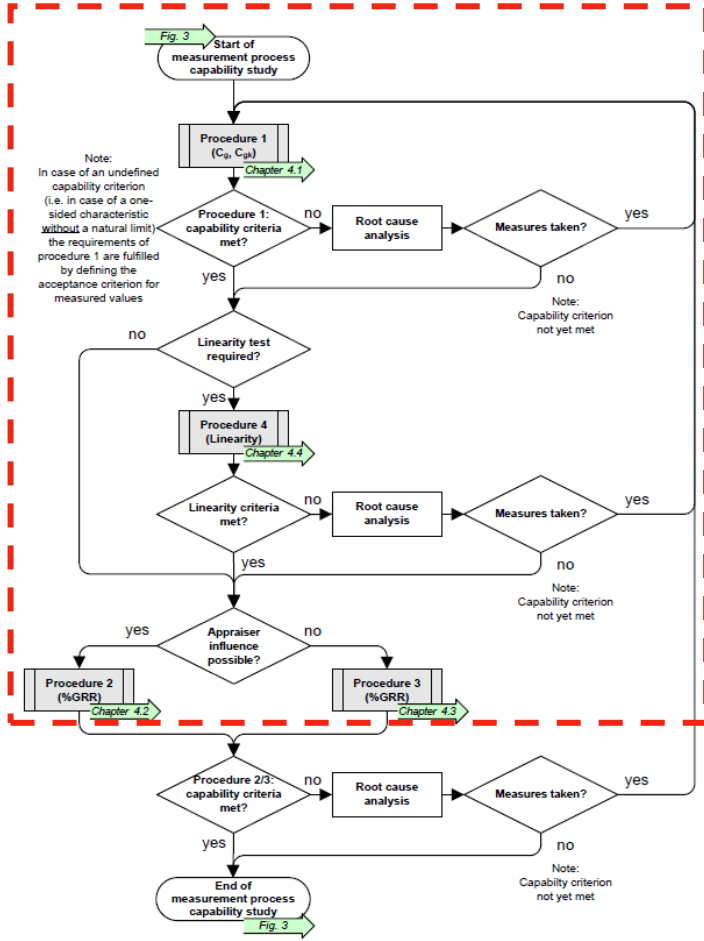
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Alternative method according to AIAG MSA



MSA methods acc to Bosch booklet 10

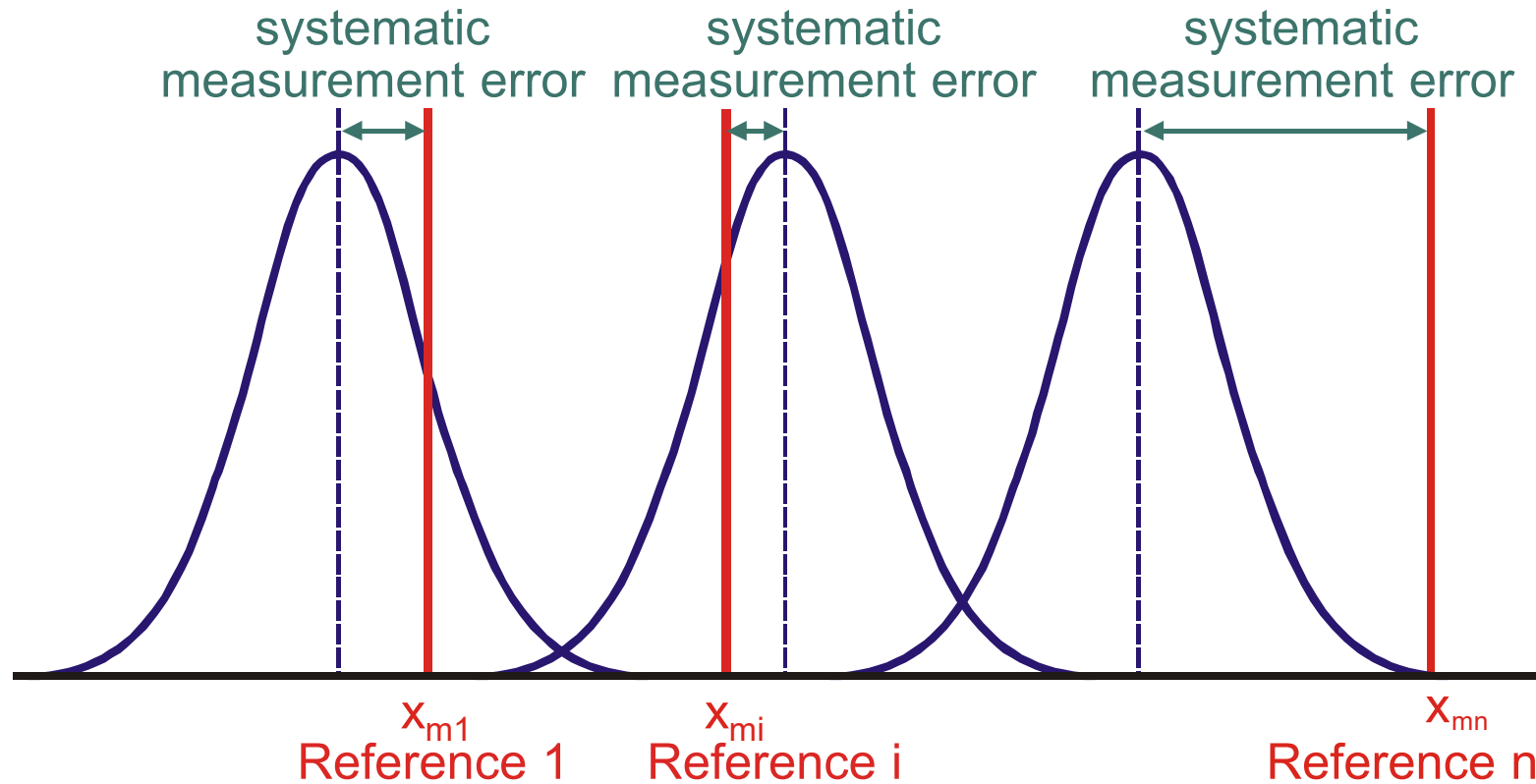
Flow charts





MSA methods acc to Bosch booklet 10

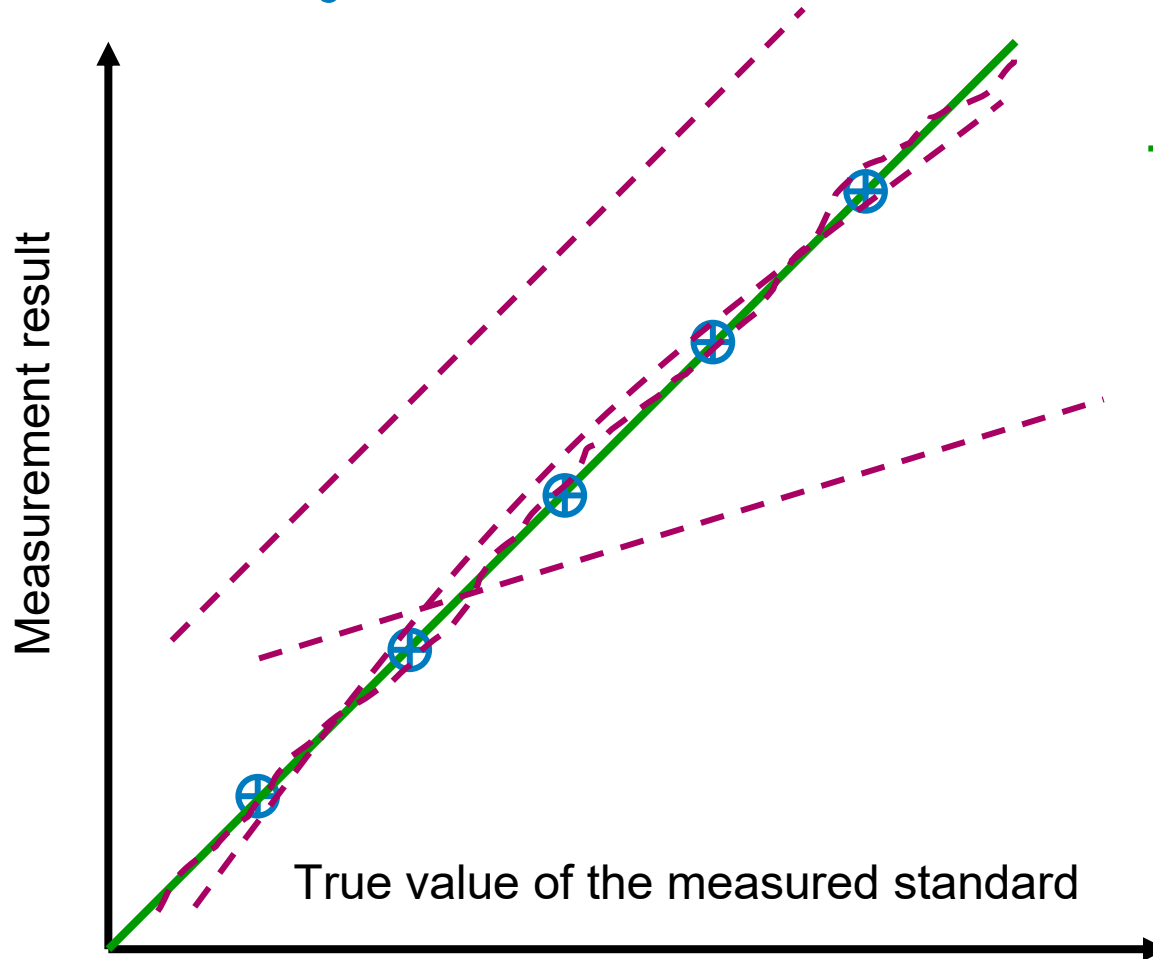
Procedure 4: linearity





MSA methods acc to Bosch booklet 10

Procedure 4: linearity



This is “linear”!

What is
not “linear”?

MSA methods acc to Bosch booklet 10

Alternative according to AIAG MSA: test for significant bias



Advantages

- Statistical significance test (1-sample t-test)
- Checks one specific component of uncertainty

Limits/weaknesses

- 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)

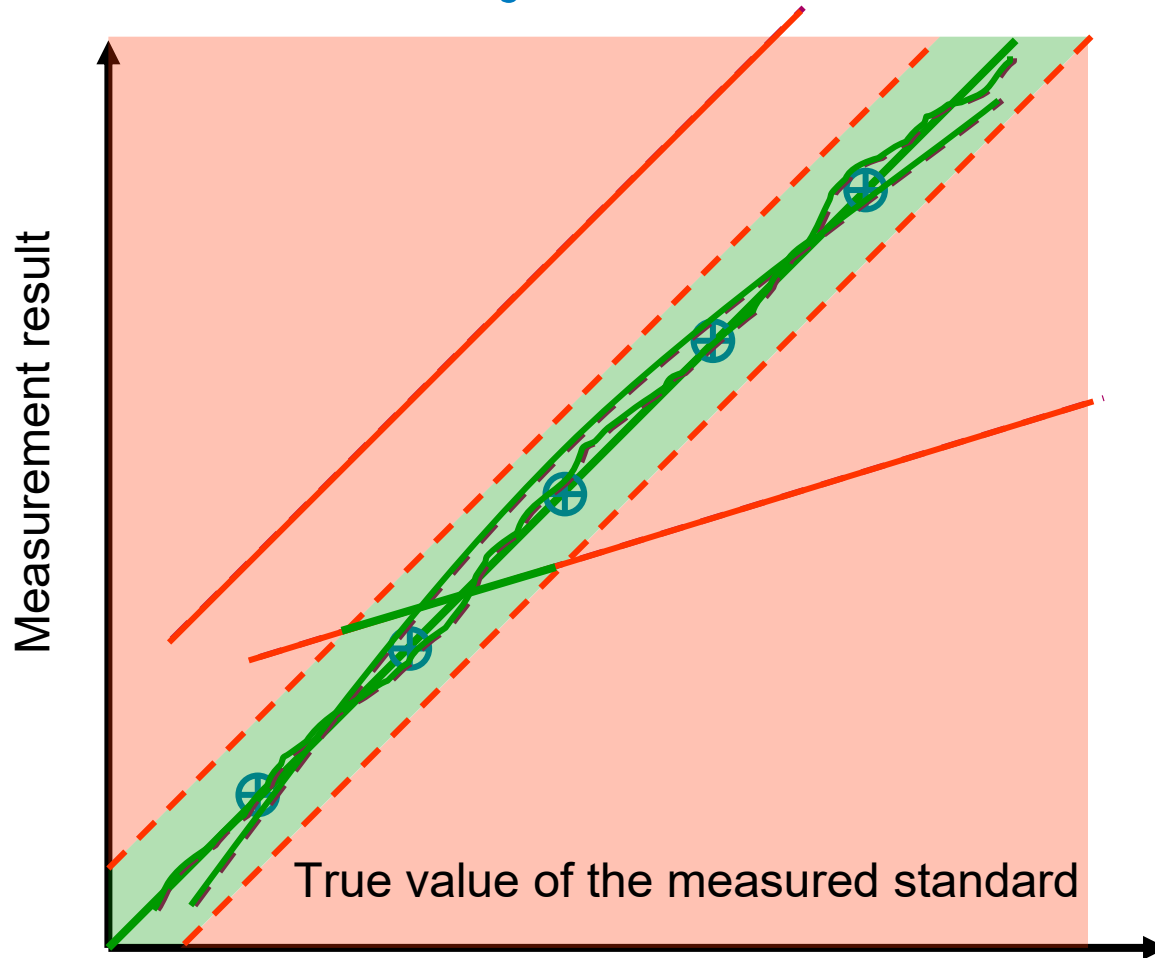
Problems in Practice

- 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”)



MSA methods acc to Bosch booklet 10

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



MSA methods acc to Bosch booklet 10

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



MSA methods acc to Bosch booklet 10

Procedure 4: linearity

- Conducting the study

Unlike the other study types, a wide variety of suggested procedures can be found in the literature.

These are mainly:

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



MSA methods acc to Bosch booklet 10

Procedure 4: linearity

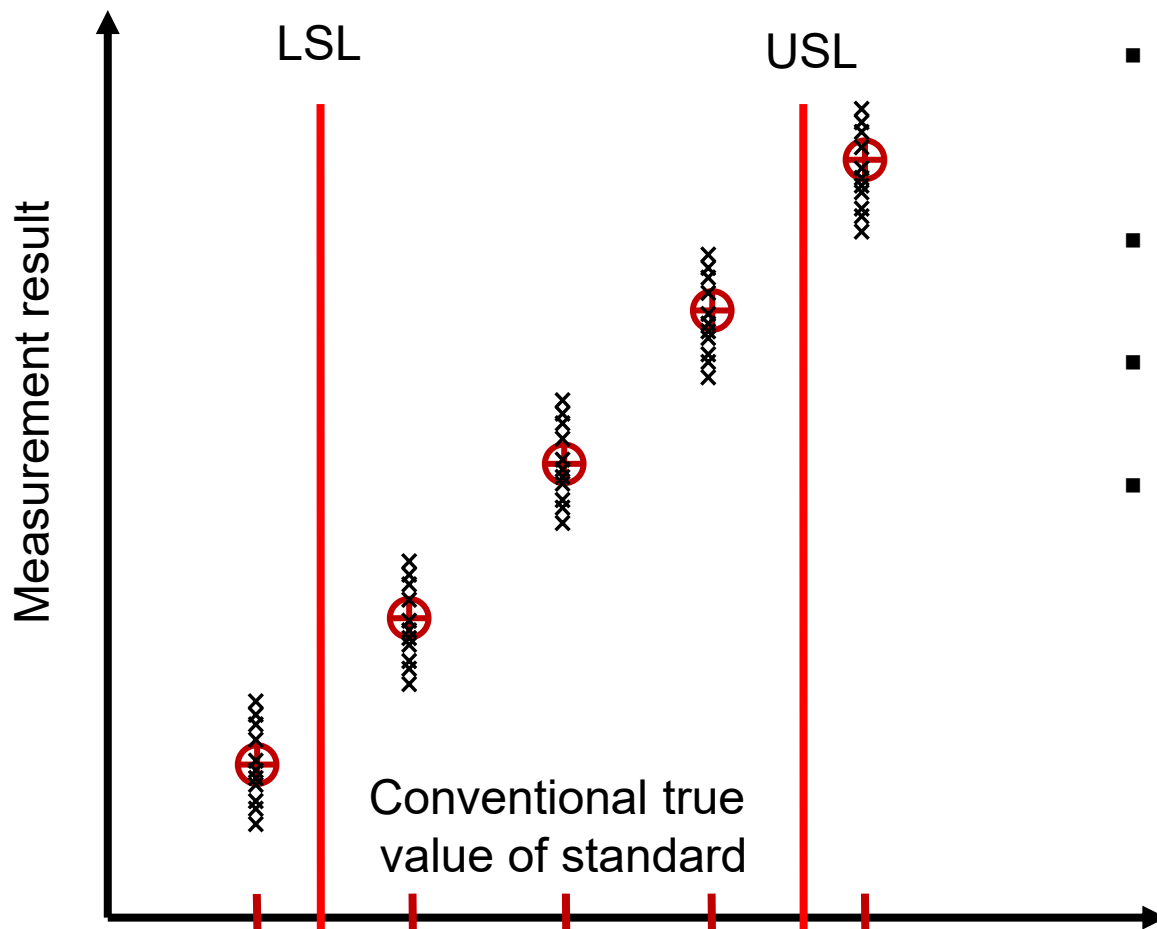
Conducting the study according to Bosch Booklet 10

- 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 C_g and C_{gk} .
-
- If only 2 standards are available, it is best for these to correspond to the limits of the tolerance range



MSA methods acc to Bosch booklet 10

Procedure 4: linearity acc. to Bosch booklet 10

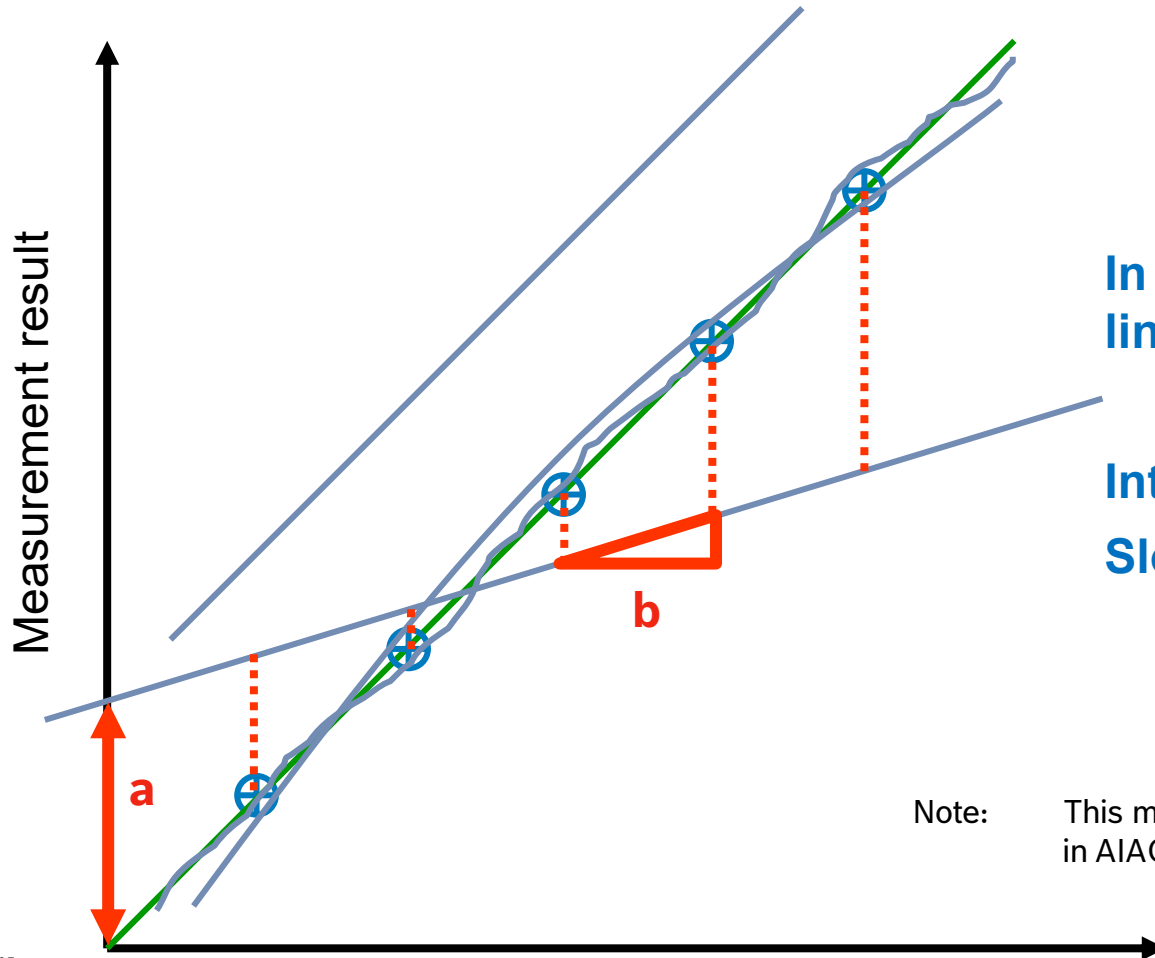


- Select at least 5 standards across the relevant measurement range
- Perform Procedure 1 for each of them
- Calculate C_g and C_{gk} as in Procedure 1
- Evaluate C_g and C_{gk} as in Procedure 1 ($C_g / C_{gk} \geq 1.33$)



MSA methods acc to Bosch booklet 10

Procedure 4: linearity using regression line



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

Intercept $a = 0$
Slope $b = 1$

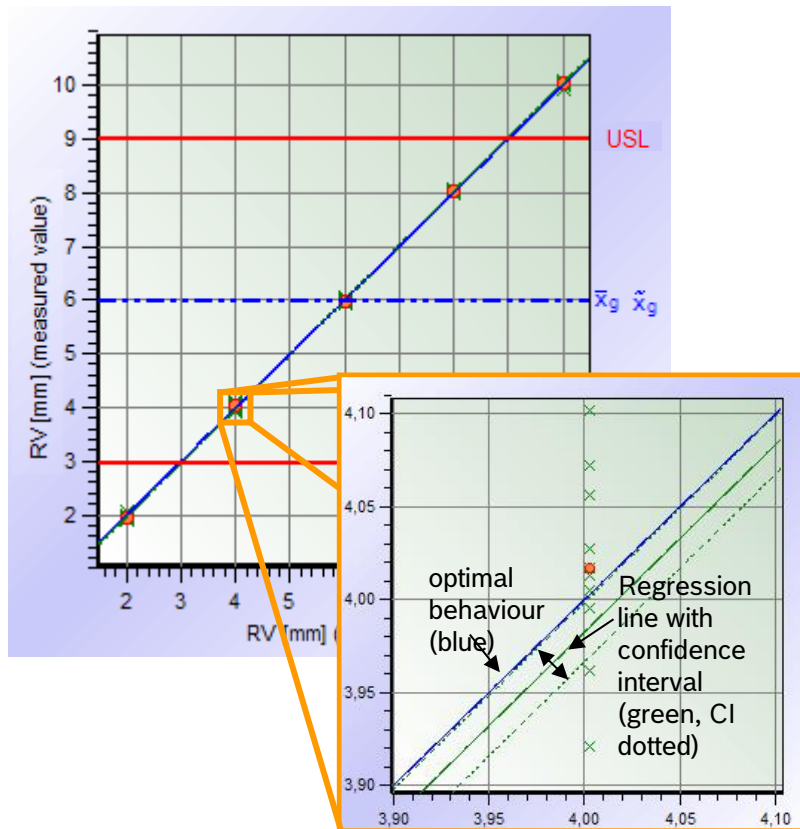
Note: This method corresponds to the method in AIAG MSA and may be a customer requirement



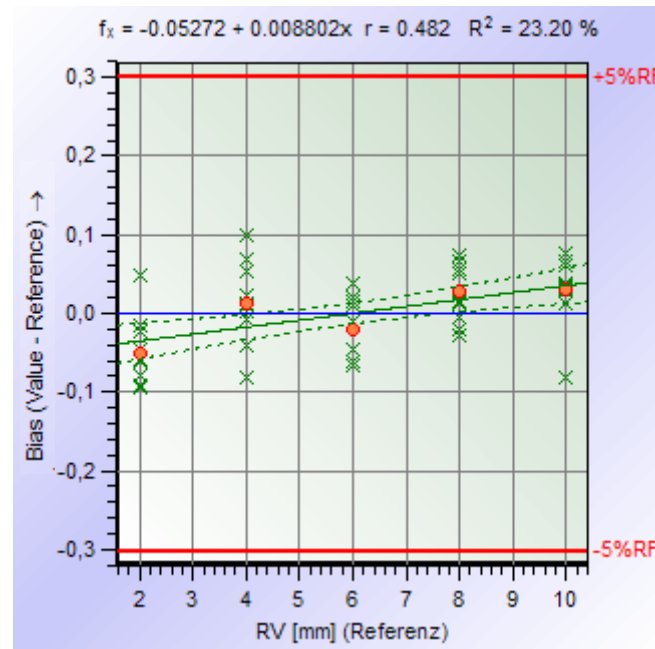
MSA methods acc to Bosch booklet 10

Procedure 4: linearity using regression line

Measured values



Measurement errors



In the ideal case:

Intercept $a = 0$

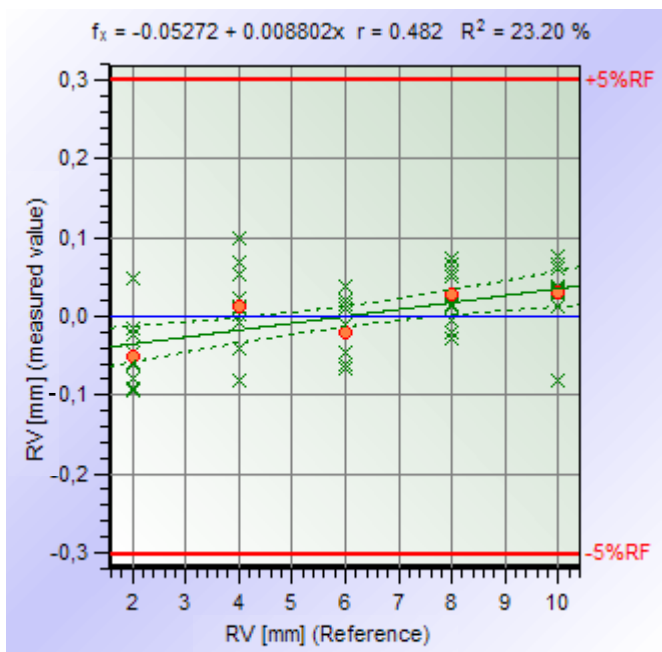
Slope $b = 0$



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Procedure 4: assessment per AIAG MSA

Measurement errors



The deviations from the ideal case are

- **significant (**)** for the slope b
- **highly significant (***)** for the intercept a

So the measurement system is unsuitable!

Does not correspond to practice!

Results of t-tests

Test of the slope		
$\alpha = 5\%$		H_0 : The slope of the regression line is equal to 0
		H_1 : The slope of the regression line is not equal to 0
Upper critical value ($\alpha = 5\%$)	= 2.00	Test result is significant ($\alpha \leq 0.1\%$)
Upper critical value ($\alpha = 1\%$)	= 2.66	
Upper critical value ($\alpha = 0,1\%$)	= 3.47	
4.50877 ***		
$H1^{***}$: The slope of the regression line is not equal to 0		
Test of the intercept		
$\alpha = 5\%$		H_0 : The intercept of the regression line is equal to 0
		H_1 : The intercept of the regression line is not equal to 0
Upper critical value ($\alpha = 5\%$)	= 2.00	Test result is significant ($\alpha \leq 0.1\%$)
Upper critical value ($\alpha = 1\%$)	= 2.66	
Upper critical value ($\alpha = 0,1\%$)	= 3.47	
4.07076 ***		
$H1^{***}$: The intercept of the regression line is not equal to 0		
Repeatability	EV: 0.0033129 ≤ 0.042772 ≤ 0.048304	%EV = ---
		Bi = 0.051500
Requirements are not fulfilled (min, t-T)		
Bosch 2018 — Procedure, Linearity		

In the ideal case:

Intercept

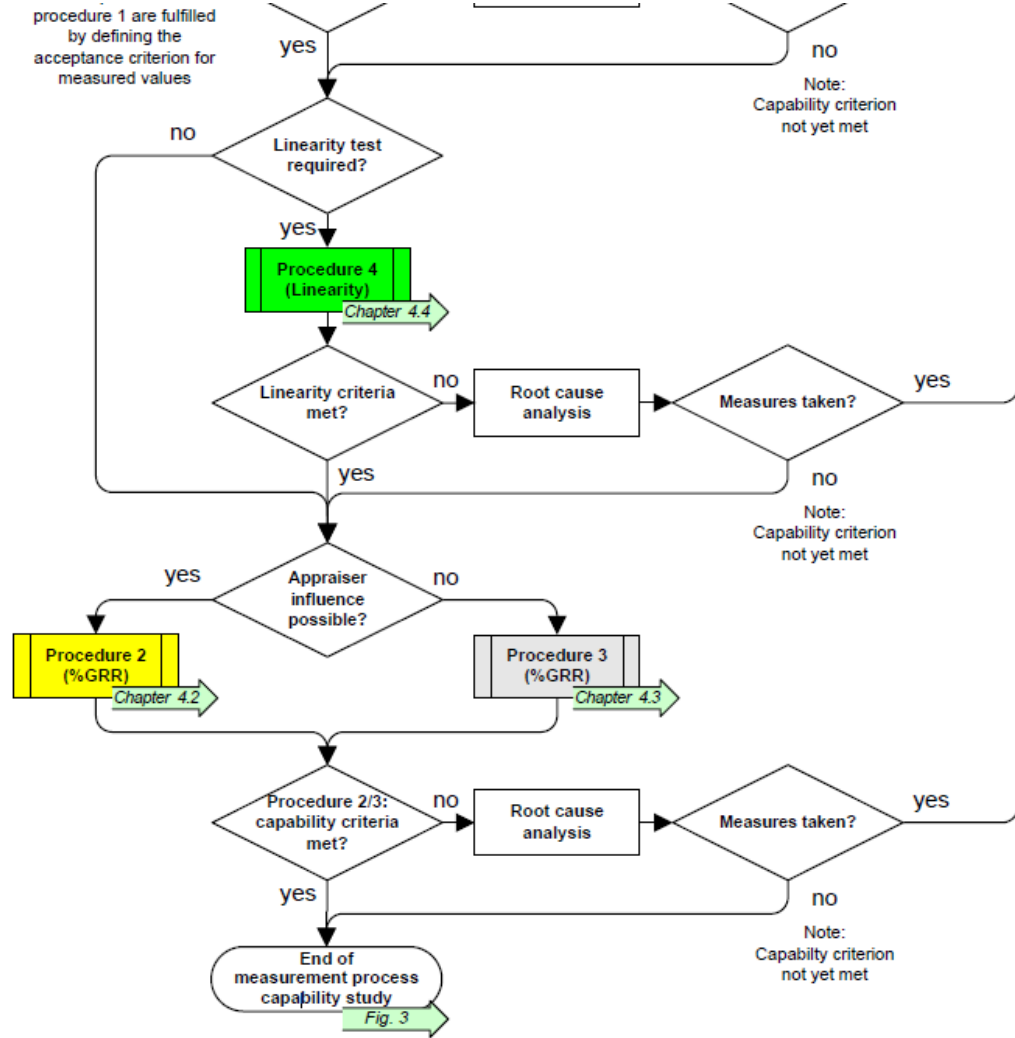
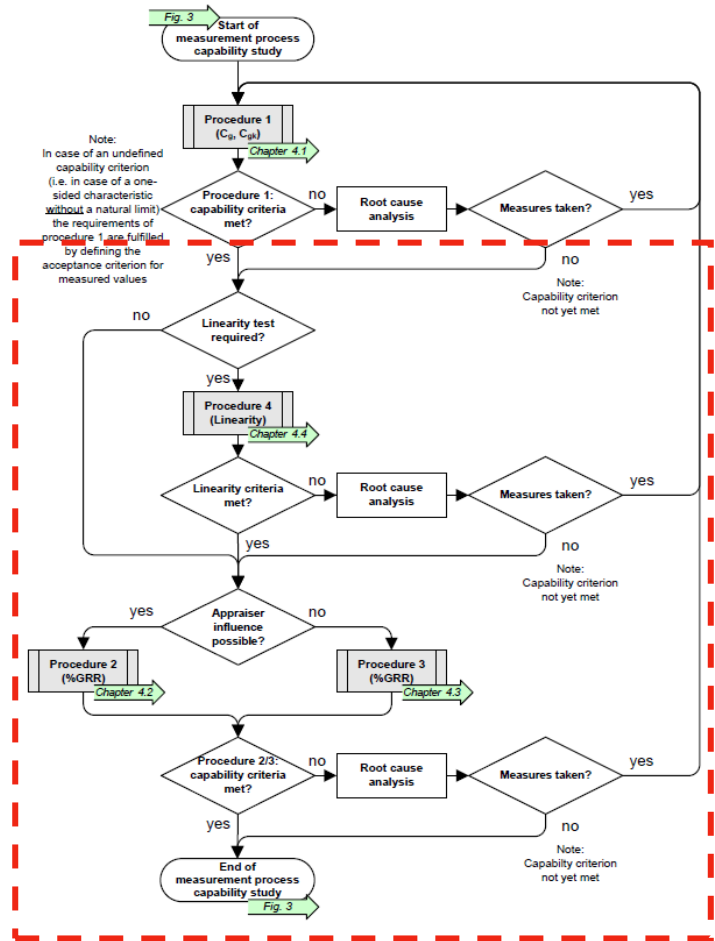
$$a = 0$$

Slope

$$b = 0$$

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Flow chart





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Procedure 2: R&R with appraiser influence

R&R = Repeatability and Reproducibility

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



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Procedure 2: R&R 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 repeatability 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.

$$\text{Parts} * \text{Operators} * \text{Trials} \geq 60$$



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Procedure 2: R&R with appraiser influence

Two analysis methods (models):

- ANOVA (ANalysis Of VAriance)
 - Recommended method
 - Identifies 3 components of variation (see following slides)
 - Requires computer assistance in practice

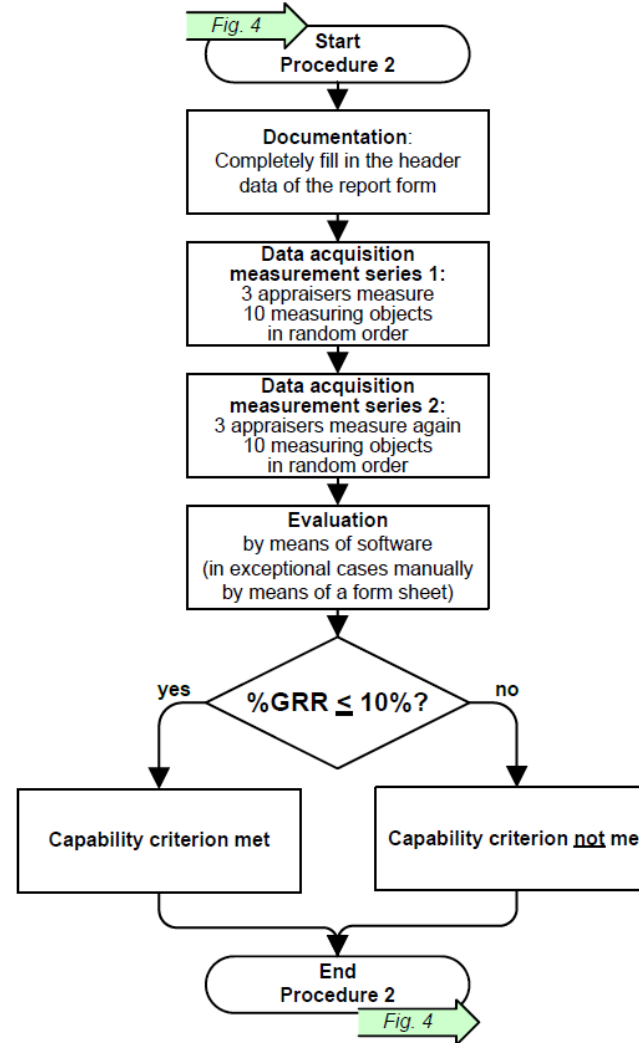
- ARM (Average Range Method)
 - Was the previous standard in the old Booklet 10
 - “Out of date and no longer recommended”
 - Identifies only 2 components of variation
 - Can be performed manually, but uses various approximations, estimates and correction factors (historical reasons)



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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



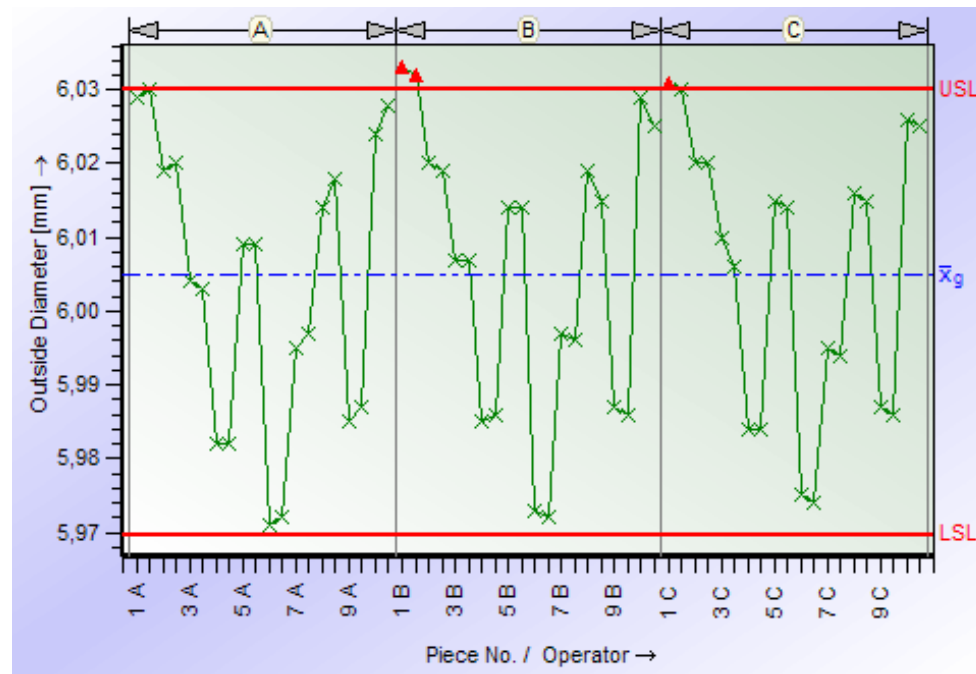


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Procedure 2: means

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)





MSA methods acc to Bosch booklet 10

Procedure 2: ANOVA, contributions to variation

Total variation is composed of

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

Teil	Appraiser A		Appraiser B		Appraiser C	
	1	2	1	2	1	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



MSA methods acc to Bosch booklet 10

Procedure 2: ANOVA, contributions to variation

Part	Appraiser A		Appraiser B		Appraiser C		\bar{x} of part, all appraisers
	1	2	1	2	1	2	
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



MSA methods acc to Bosch booklet 10

Procedure 2: ANOVA, contributions to variation

Part	Appraiser A		Appraiser B		Appraiser C		\bar{x} of part all appraisers
	1	2	1	2	1	2	
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
	6,0039		6,0058		6,0054		
	Variance of appraisers		\bar{x} of each appraiser $s^2_{AV} = 9,86E-07$				

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



MSA methods acc to Bosch booklet 10

Procedure 2: ANOVA, contributions to variation

Part	Appraiser A		\bar{x} of part at appraiser A	Appraiser B		\bar{x} of part at appraiser B	Appraiser C		\bar{x} of part at appraiser C	\bar{x} of part all appraisers	Variance of means \bar{x} of each part
	1	2		1	2		1	2			
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	$s^2_{IA10} = 5,83333E-07$
6,0039				6,0058			6,0054				Minus PV and AV $\Rightarrow s^2_{IA}$
				\bar{x} of each appraiser							

Total variation is composed of

- Part-to-part variation \Rightarrow PV Part Variation
- Variation between appraisers \Rightarrow AV Appraiser Variation
- Interaction between appraiser and part** \Rightarrow **IA Interaction**
- Measuring equipment variation (“the rest”)



MSA methods acc to Bosch booklet 10

Procedure 2: ANOVA, contributions to variation

Part	Appraiser A		\bar{x} of part at appraiser A	Appraiser B		\bar{x} of part at appraiser B	Appraiser C		\bar{x} of part at appraiser C	\bar{x} of part all appraisers
	1	2		1	2		1	2		
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
	6,0039			6,0058			6,0054			
				\bar{x} of each appraiser						
	Variance of all measurements			$s^2_{EV} = 0,000352$			Minus variation from PV, AV and IA			

Total variation is composed of

- Part-to-part variation ⇒ PV Part Variation
- Variation between appraisers ⇒ AV Appraiser Variation
- Interaction between appraiser and part ⇒ IA Interaction
- **Measuring equipment variation (“the rest”)** **⇒ EV Equipment Variation**



MSA methods acc to Bosch booklet 10

Procedure 2: ANOVA, contributions to variation

Part	Appraiser A		\bar{x} of part at appraiser A	Appraiser B		\bar{x} of part at appraiser B	Appraiser C		\bar{x} of part at appraiser C	\bar{x} of part all appraisers
	1	2		1	2		1	2		
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
	6,0039			6,0058			6,0054			
				\bar{x} of each appraiser						

- AV = $\hat{\sigma}_{AV}$ Appraiser Variation
 - IA = $\hat{\sigma}_{IA}$ Interaction
 - EV = $\hat{\sigma}_{EV}$ Equipment Variation
 - \Rightarrow GRR = $\hat{\sigma}_{GRR}$ Gage Repeatability & Reproducibility
- } $GRR = \sqrt{EV^2 + AV^2 + IA^2}$



MSA methods acc to Bosch booklet 10

Procedure 2: ANOVA, contributions to variation

	Variance	Standard dev.	Confidence level 1 - α = 95%			
Repeatability	0.0000023556	0.0015348	EV: 0.0012799	\leq 0.0015348	\leq 0.0019174	%EV = 15.35%
Reproducibility	0,00000086806	0.00093169	AV: 0.00035980	\leq 0.00093169	\leq 0.006229	%AV = 9.32%
Interaction	pooling	pooling	IA:	\leq	\leq	%IA = ---
R&R	0.0000032236	0.0017954	GRR: 0.0015827	\leq 0.0017954	\leq 0.0064169	%GRR = 17.95%
Part variation	0.00038084	0.019515	PV: 0.0126070	\leq 0.019515	\leq 0.036405	%PV = 195.15%
Total variation	0.00038406	0.019598	TV:	0.020		

Test design		Reference quantity	
Number of trials	= 2	Process variation	= 0
Number of appraisers	= 3	Tolerance	= 0.060
Number of parts	= 10	Required Cp value	=

Resolution	%RE	=	1.67%	
Number of distinct categories (ndc)	ndc	=	15	
Repeatability & Reproducibility	%GRR	=	17.95%	
Minimum reference figure f. capable measur. system	$T_{min} (\%GRR)$	=	0.108	
Min. ref. fig. f. conditionally capable measur. system	$T_{min} (\%GRR)$	=	0.0250	

<ul style="list-style-type: none"> • AV • IA • EV • \Rightarrow GRR 	<ul style="list-style-type: none"> = $\hat{\sigma}_{AV}$ = $\hat{\sigma}_{IA}$ = $\hat{\sigma}_{EV}$ = $\hat{\sigma}_{GRR}$ 	<ul style="list-style-type: none"> Appraiser Variation Interaction Equipment Variation Gage Repeatability & Reproducibility 	$GRR = \sqrt{EV^2 + AV^2 + IA^2}$	
				Measurement system is conditic
				Bosch 2018

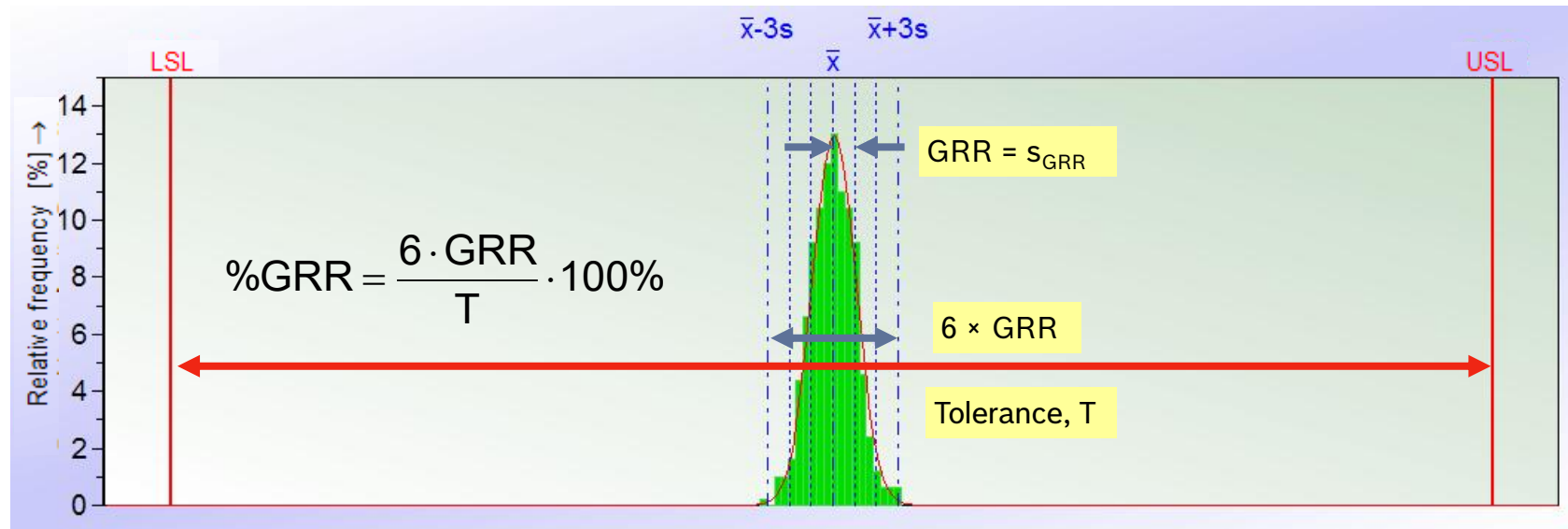
■ Composition of GRR



MSA methods acc to Bosch booklet 10

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 = $6 s = 6 \times \text{GRR}$
- The tolerance is used as a reference value

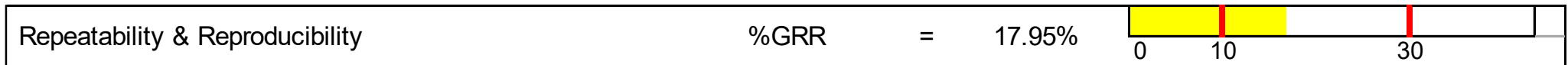




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Procedure 2: requirements for %GRR

- $\%GRR \leq 10\%$ capable
- $10\% < \%GRR \leq 30\%$ conditionally capable
- $\%GRR > 30\%$ not capable



MSA methods acc to Bosch booklet 10

Procedure 2: report



Documentation

Run chart of deviations

Measurement results

Statistics and assessment

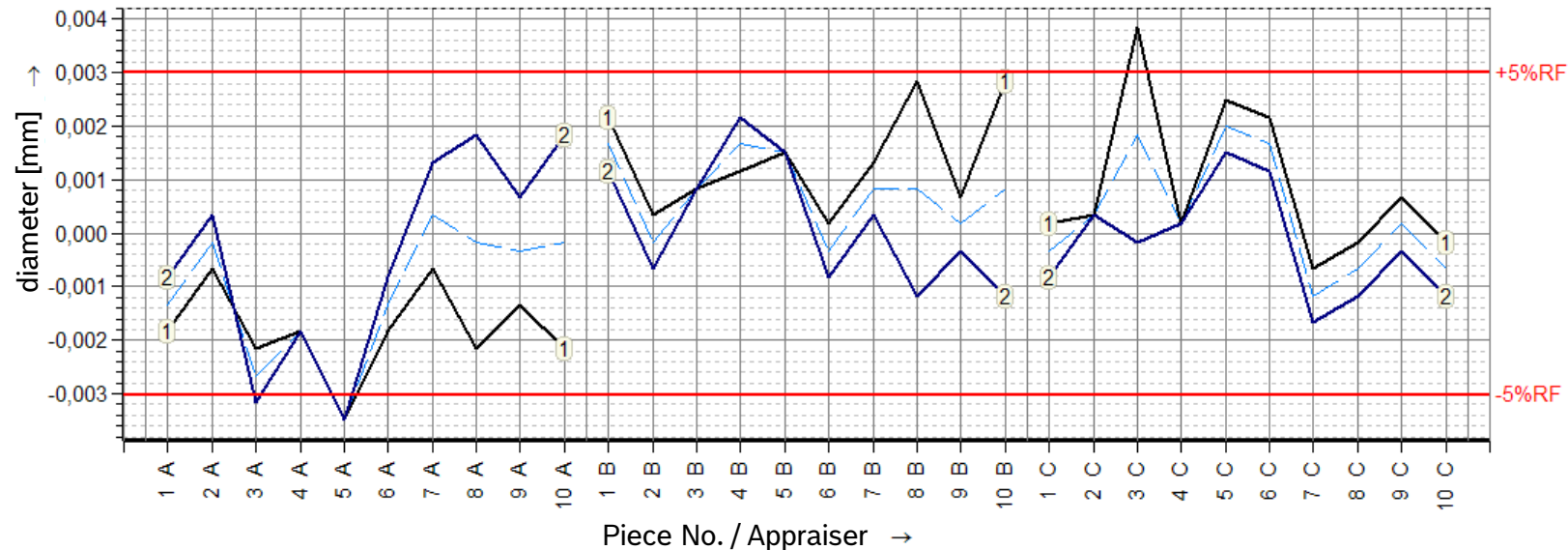
BOSCH		Measurement System Analysis Procedure 2			Sheet 1 / 1							
Area : MSE3	Operation : Mating corpus/needle	Characteristic : Corpus diameter										
Group/Dptm. : MOE7	Machine : PAKO 8	Char. No. : 1										
Workshop/sect. : W450	Machine No. : 1004537	Nominal value : 6.000										
Product : Injector	Test station : JML0583W004	Lower allowance : -0.030										
Part : Hole type nozzle	Gage : JML0583W001	Upper allowance : 0.030										
Article number : 0 433 171 914	Gage No. : 6702779430001	Tolerance : 0.060										
Change status : 20.01.2019	Gage Manuf. : BaP	Unit : mm										
	Resolution : 0.001											
Comment : Manual operation; room temperature 20.2 °C												
Standard: Standard No.: Standard/Ref. value:												
i	X _{A,1}	X _{A,2}	X _{G,1}	S _{G,1}	X _{B,1}	X _{B,2}	X _{G,2}	S _{G,2}	X _{C,1}	X _{C,2}	X _{G,3}	S _{G,3}
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	6.030	6.0035	0.0007	6.007	6.007	6.007	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	6.014	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	6.017	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	6.027	0.0028	6.026	6.025	6.0255	0.0007
		Variance	Standard dev.		Confidence level 1 - α = 95%							
Repeatability		0.000023556	0.0015348		EV: 0.0012799 ≤ 0.0015348 ≤ 0.0019174			%EV = 15.35%				
Reproducibility		0.0000086806	0.00093169		AV: 0.00035980 ≤ 0.00093169 ≤ 0.006229			%AV = 9.32%				
Interaction		pooling	pooling		IA: ≤ ≤ ≤			%IA = ---				
R&R		0.000032236	0.0017954		GRR: 0.0015827 ≤ 0.0017954 ≤ 0.0064169			%GRR = 17.95%				
Part variation		0.00038084	0.019515		PV: 0.0126070 ≤ 0.019515 ≤ 0.036405			%PV = 195.15%				
Total variation		0.00038406	0.019598		TV: 0.020							
Test design				Reference quantity								
Number of trials = 2				Process variation = 0								
Number of appraisers = 3				Tolerance = 0.060								
Number of parts = 10				Required Cp value =								
Resolution		%RE = 1.67%		0		5						
Number of distinct categories (ndc)		ndc = 15		0		5						
Repeatability & Reproducibility		%GRR = 17.95%		0		10		30				
Minimum reference figure f. capable measur. system				T _{min} (%GRR) = 0.108								
Min. ref. fig. f. conditionally capable measur. system				T _{min} (%GRR) = 0.0359								
Measurement system is conditionally capable (RE, C _p , C _{gk})												
Bosch 2018 — Procedure 2												

MSA methods acc to Bosch booklet 10

Procedure 2: report



Run chart of deviations



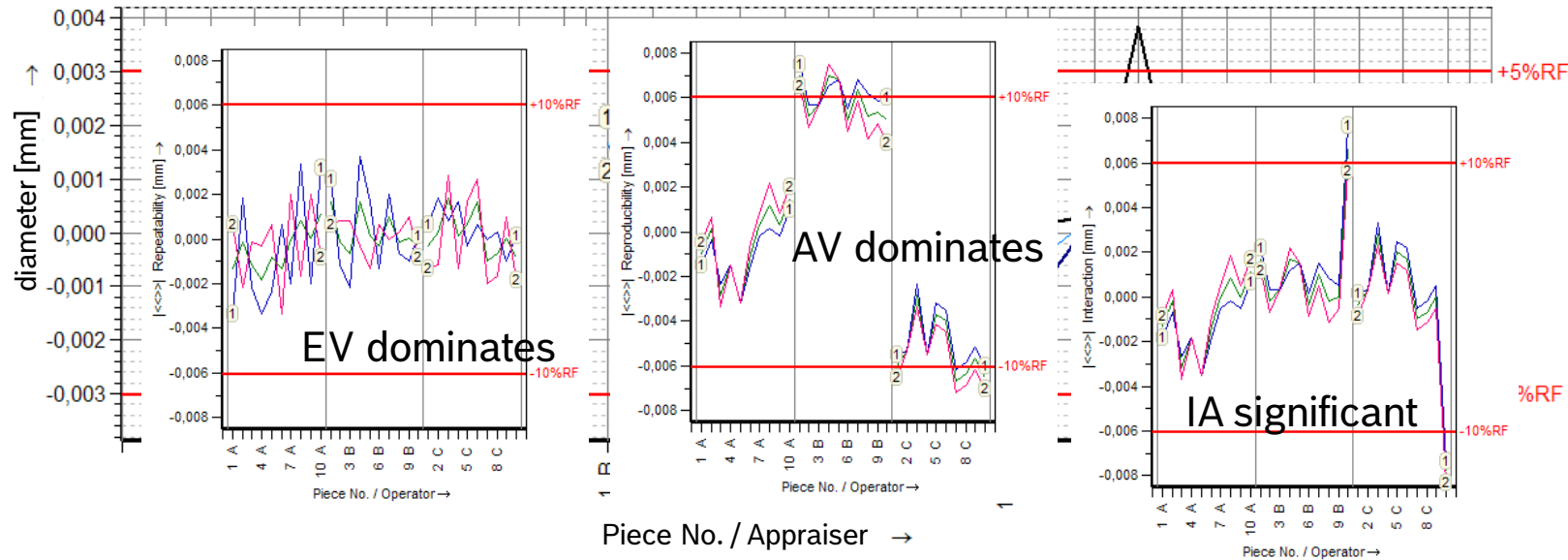
- Deviation of individual measurement from the mean of all measurements for the relevant part
- Graphical representation of the variation statistics EV, AV und IA

MSA methods acc to Bosch booklet 10

Procedure 2: report



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



MSA methods acc to Bosch booklet 10

Procedure 2: report, statistics

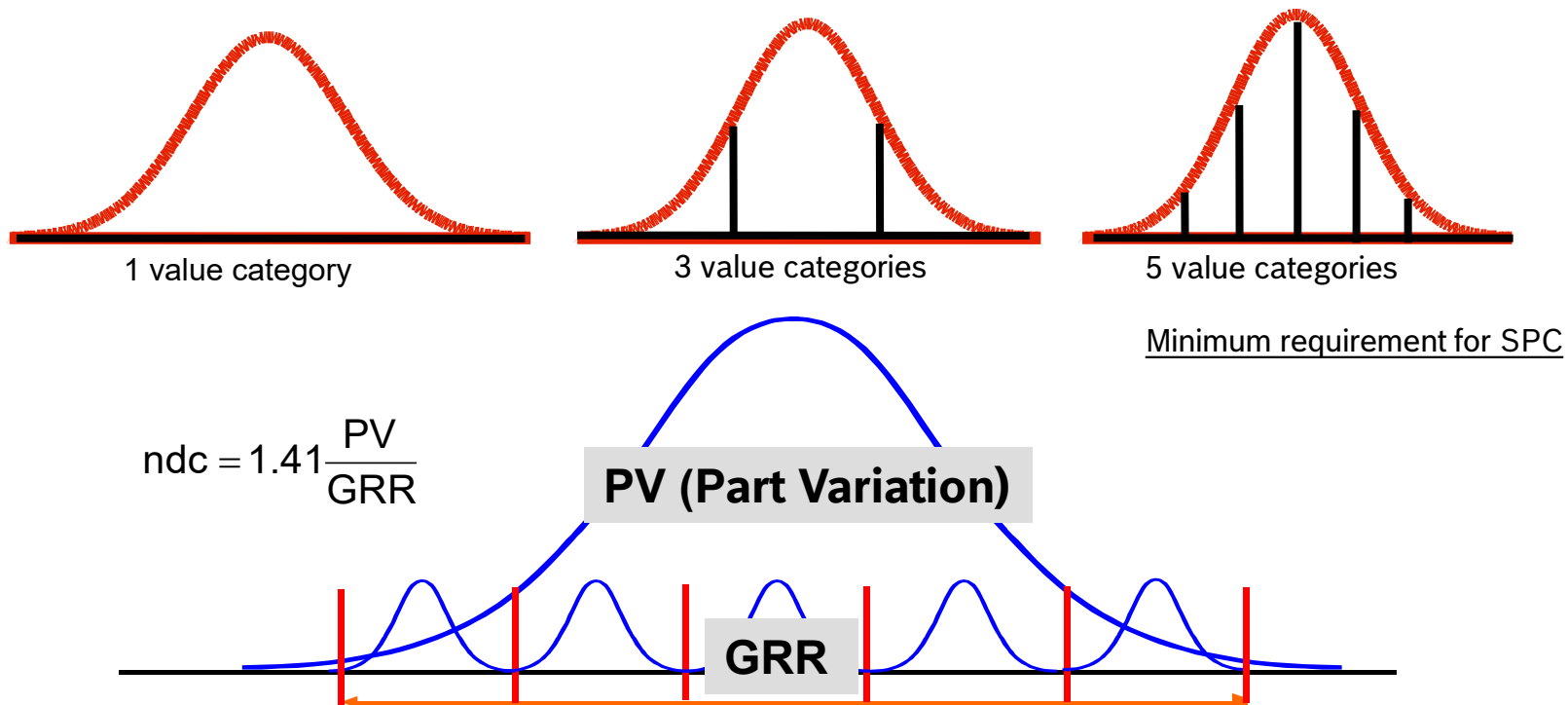
	Variance	Standard dev.	Confidence level 1 - α = 95%			
Repeatability	0.0000023556	0.0015348	EV:	0.0012799 ≤ 0.0015348 ≤ 0.0019174	%EV	= 15.35%
Reproducibility	0,00000086806	0.00093169	AV:	0.00035980 ≤ 0.00093169 ≤ 0.006229	%AV	= 9.32%
Interaction	pooling	pooling	IA:	≤ ≤	%IA	= ---
R&R	0.0000032236	0.0017954	GRR:	0.0015827 ≤ 0.0017954 ≤ 0.0064169	%GRR	= 17.95%
Part variation	0.00038084	0.019515	PV:	0.0126070 ≤ 0.019515 ≤ 0.036405	%PV	= 195.15%
Total variation	0.00038406	0.019598	TV:	0.020		
Test design			Reference quantity			
Number of trials	=	2	Process variation		=	0
Number of appraisers	=	3	Tolerance		=	0.060
Number of parts	=	10	Required Cp value		=	
Resolution	%RE	=	1.67%			
Number of distinct categories (ndc)	ndc	=	15			
Repeatability & Reproducibility	%GRR	=	17.95%			
Minimum reference figure f. capable measur. system	T _{min} (%GRR)	=	0.108			
Min. ref. fig. f. conditionally capable measur. system	T _{min} (%GRR)	=	0.0359			
Measurement system is conditionally capable (RE, C _g , C _{gk})						
Bosch 2018 — Procedure 2						



MSA methods acc to Bosch booklet 10

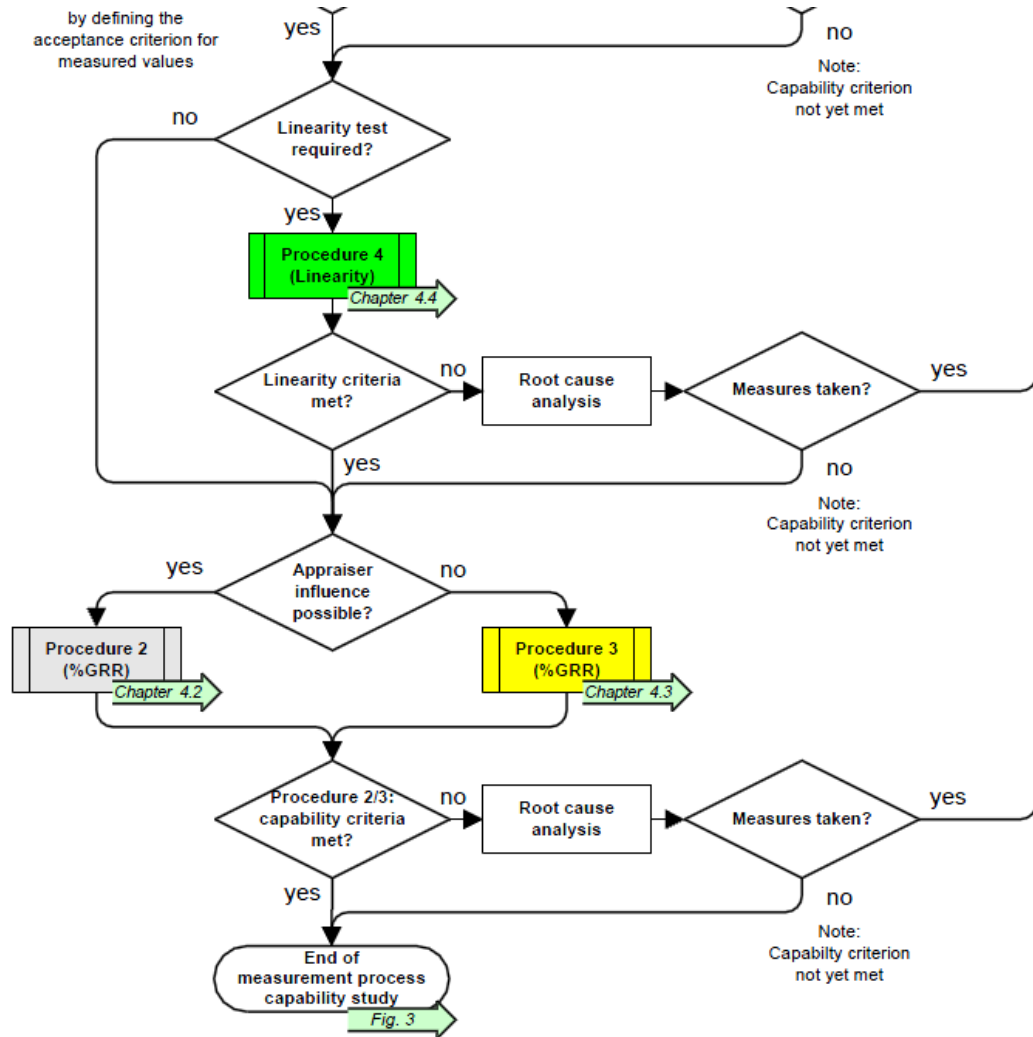
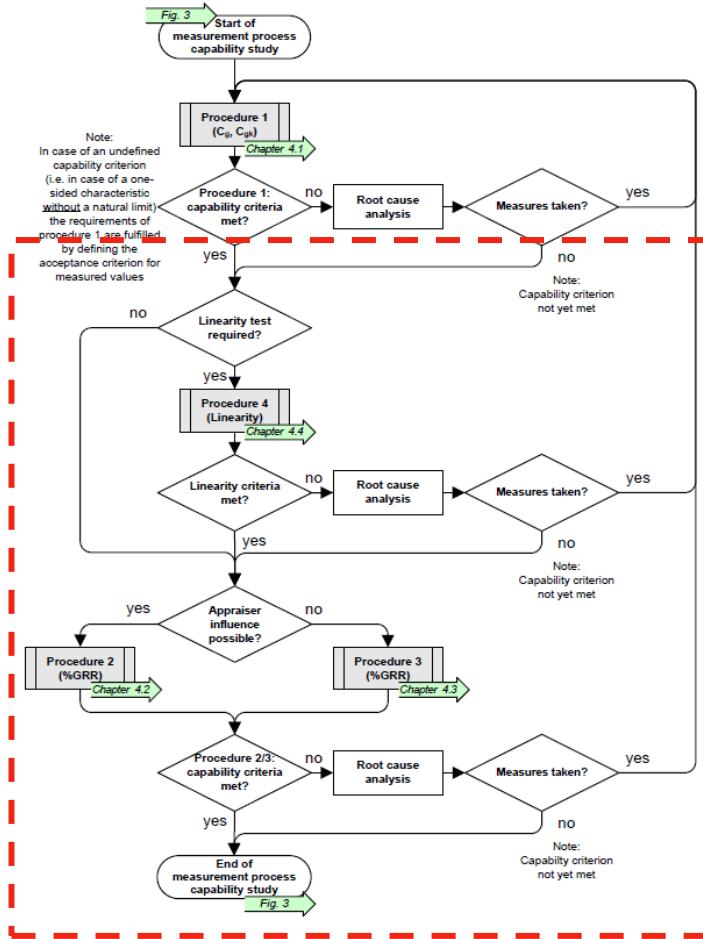
Procedure 2: number of distinct categories ndc

- Requirement: $ndc \geq 5$



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Flow chart





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Procedure 3: R&R without appraiser influence

R&R = Repeatability and Reproducibility

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.



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Procedure 3: R&R 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 repeatability measurable,
- in random sequence,
- using at least 2 measurement series,
- under repeatability conditions and at defined measurement points.

Parts * Trials \geq 50

Analysis

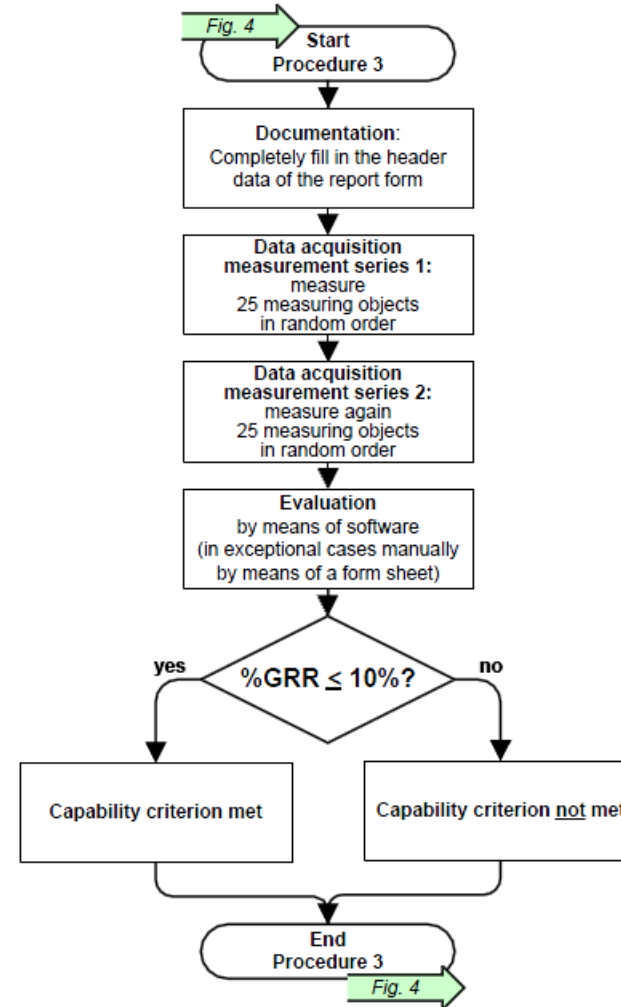
- Per Procedure 2 using ANOVA
- ARM analysis “out of date and no longer recommended”



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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





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Procedure 3: ANOVA

	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	6,022	6,019	6,0195	6,022	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

↓
25

Total variation is composed of

- Part-to-part variation \Rightarrow PV Part Variation
- ~~– Variation between appraisers \Rightarrow AV Appraiser Variation~~
- ~~– Interaction between appraiser and part \Rightarrow IA Interaction~~
- Measuring equipment variation (“the rest”) \Rightarrow EV Equipment Variation

MSA methods acc to Bosch booklet 10

Procedure 3: report



Documentation

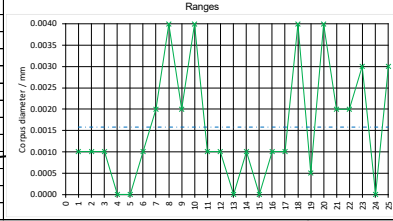
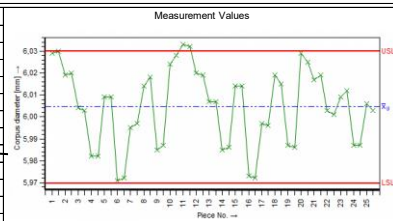
Run chart of individual values

Measurement results

Run chart of ranges

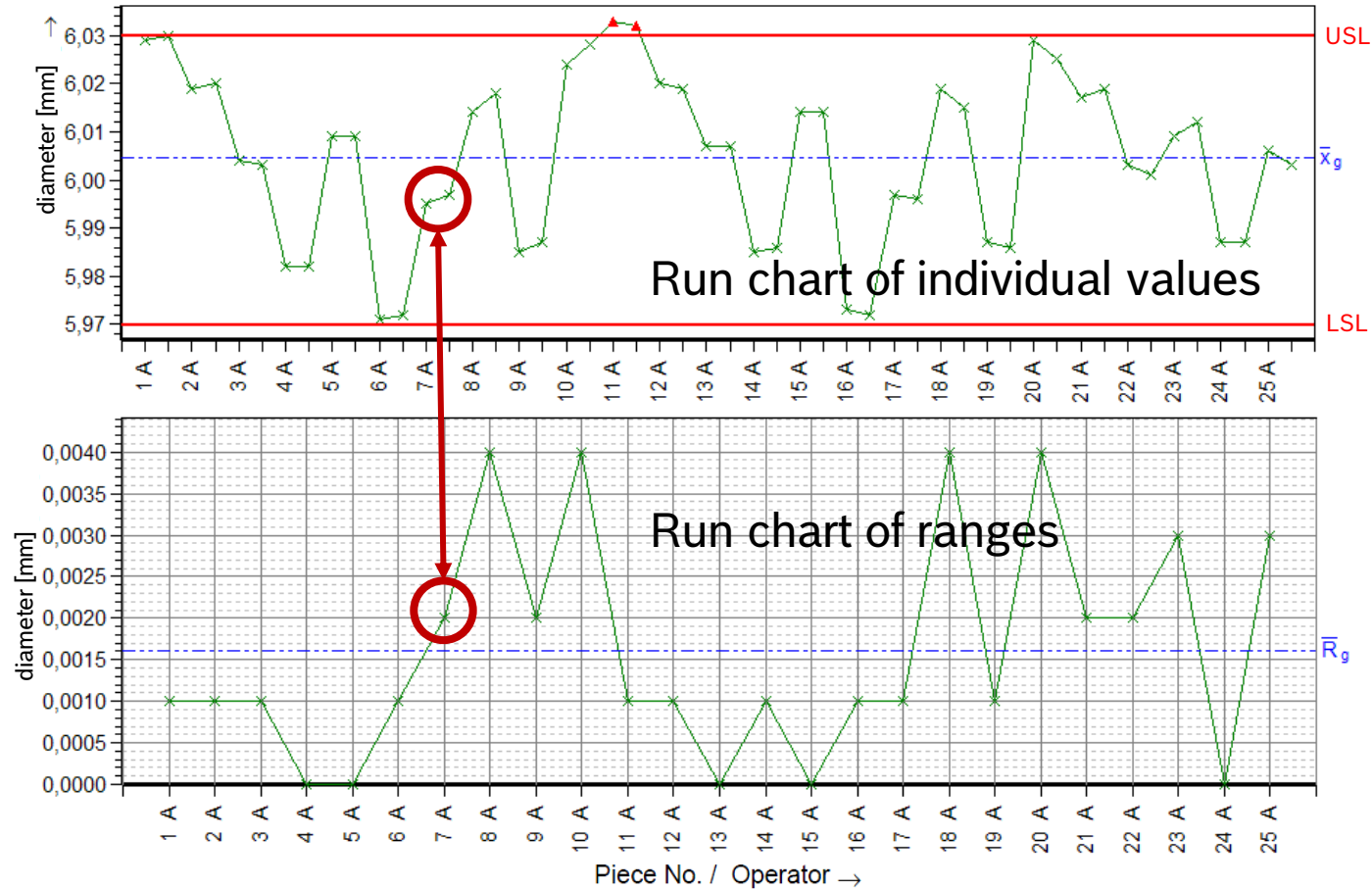
Statistics and assessment

BOSCH		Measurement System Analysis Procedure 3		Sheet 1 / 1																									
Area : MSE3	Operation : Mating corpus/needle	Characteristic : Corpus diameter																											
Group/Dptm. : MOE7	Machine : PAKO 9	Char. No. : 1																											
Workshop/sect. : W450	Machine No. : 1003521	Nominal value : 6.000																											
Product : Injector	Test station : JML0563W001	Lower allowance : -0.030																											
Part : Hole type nozzle	Gage : JML0563W003	Upper allowance : 0.030																											
Article number : 0 433 171 914	Gage No. : 6702779430004	Tolerance : 0.060																											
Change status : 20.01.2019	Gage Manuf. : BaP	Unit : mm																											
Resolution : 0.001																													
Comment :																													
Standard:		Standard No. : Standard/Ref. value:																											
1	$X_{A,1}$	$X_{A,2}$	$S_{s,j}$	$S_{s,j}$																									
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	5.972	5.9715	0.0007																									
7	5.995	5.997	5.9960	0.0014																									
8	6.014	6.018	6.0160	0.0020																									
9	5.985	5.987	5.9860	0.0014																									
10	6.024	6.028	6.0260	0.0028																									
11	6.033	6.032	6.0325	0.0007																									
12	6.020	6.019	6.0195	0.0007																									
13	6.007	6.007	6.0070	0.0000																									
14	5.985	5.986	5.9855	0.0007																									
15	6.014	6.014	6.0140	0.0000																									
16	5.973	5.972	5.9725	0.0007																									
17	5.997	5.996	5.9965	0.0007																									
18	6.019	6.015	6.0170	0.0028																									
19	5.987	5.9865	5.9865	0.0007																									
20	6.029	6.025	6.0270	0.0028																									
21	6.017	6.019	6.0180	0.0014																									
22	6.003	6.001	6.0020	0.0014																									
23	6.009	6.012	6.0105	0.0021																									
24	5.987	5.987	5.9870	0.0000																									
25	6.006	6.003	6.0045	0.0021																									
<table border="1"> <thead> <tr> <th></th> <th>Variance</th> <th>Standard dev.</th> <th colspan="2">Confidence level 1 - α = 95%</th> </tr> </thead> <tbody> <tr> <td>Repeatability</td> <td>0.0000021600</td> <td>0.0014697</td> <td>EV: 0.0011526 \leq 0.0014697 \leq 0.0020288</td> <td>%EV = 14.70%</td> </tr> <tr> <td>R&R</td> <td>0.0000021600</td> <td>0.0014697</td> <td>GRR: 0.0011526 \leq 0.0014697 \leq 0.0020288</td> <td>%GRR = 14.70%</td> </tr> <tr> <td>Part variation</td> <td>0.0003133200</td> <td>0.017701</td> <td>PV: 0.0126070 \leq 0.0177010 \leq 0.0266200</td> <td>%PV = 177.01%</td> </tr> <tr> <td>Total variation</td> <td>0.0003840600</td> <td>0.017762</td> <td>TV: 0.018</td> <td></td> </tr> </tbody> </table>						Variance	Standard dev.	Confidence level 1 - α = 95%		Repeatability	0.0000021600	0.0014697	EV: 0.0011526 \leq 0.0014697 \leq 0.0020288	%EV = 14.70%	R&R	0.0000021600	0.0014697	GRR: 0.0011526 \leq 0.0014697 \leq 0.0020288	%GRR = 14.70%	Part variation	0.0003133200	0.017701	PV: 0.0126070 \leq 0.0177010 \leq 0.0266200	%PV = 177.01%	Total variation	0.0003840600	0.017762	TV: 0.018	
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Versuchsplan		Reference quantity																											
Number of trials	= 2	Process variation	=	0																									
Number of parts	= 25	Tolerance	=	0.060																									
		Required Cp value	=																										
Resolution	%RE = 0.0167																												
Number of distinct categories (ndc)	ndc = 17																												
Repeatability & Reproducibility	%GRR = 14.7%																												
Minimum reference figure f. capable measur. system	$T_{min} (\%GRR)$ = 0.0882																												
Min. ref. fig. f. conditionally capable measur. system	$T_{min} (\%GRR)$ = 0.0294																												
Measurement system is conditionally capable (%RE, min. %GRR)																													
Bosch 2018 — Procedure 3																													



MSA methods acc to Bosch booklet 10

Procedure 3: report





MSA methods acc to Bosch booklet 10

Procedure 3: calculate statistics

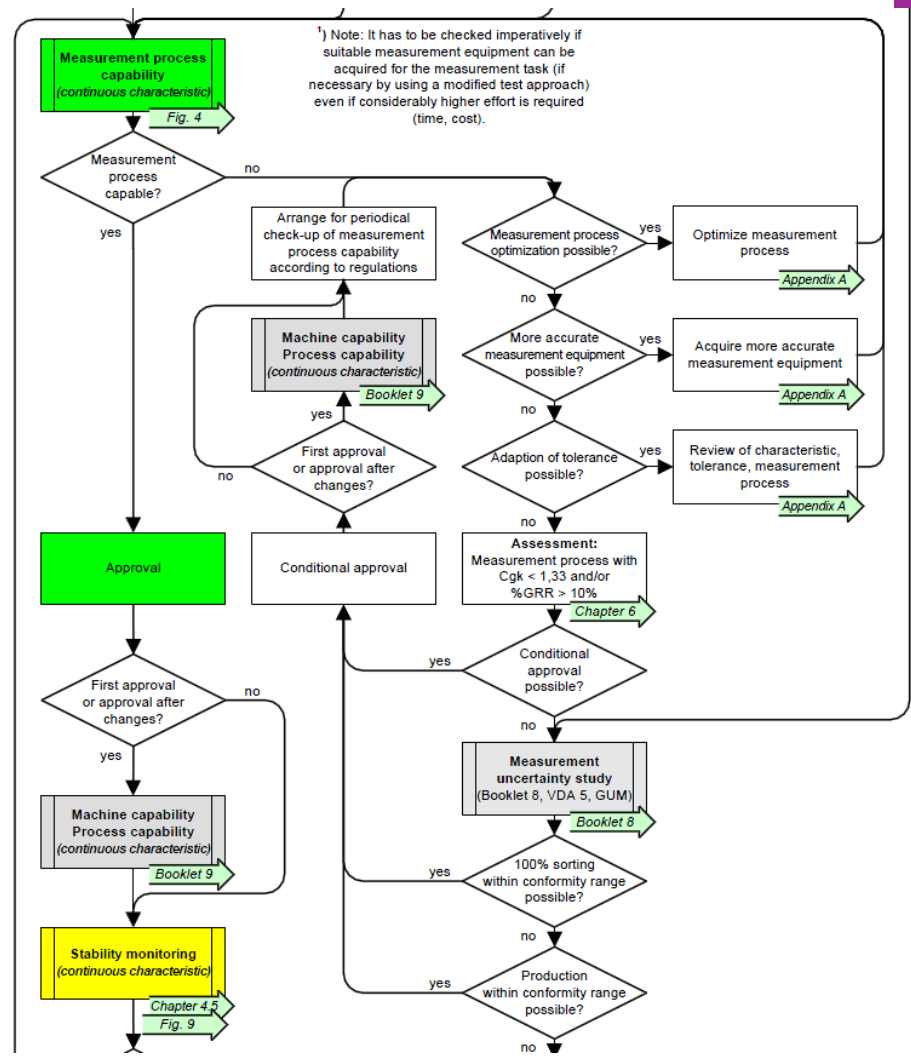
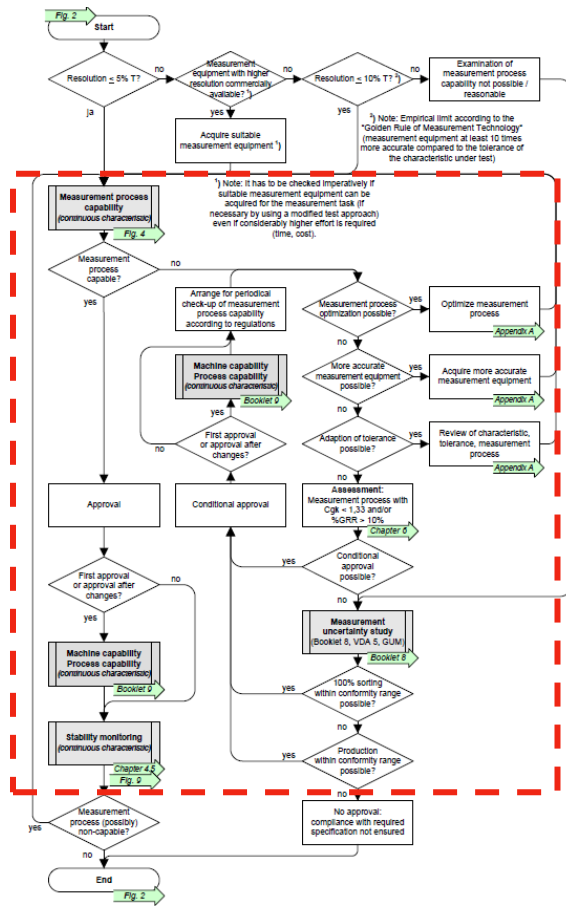
n	XA.1	XA.2	\bar{x}_{gj}	s_{gj}		
1	6,029	6,030	6,0295	0,0007		
2	6,019	6,020	6,0195	0,0007		
3	6,004	6,003	6,0035	0,0007		
4	5,982	5,982	5,9820	0,0000		
5	6,009	6,009	6,0090	0,0000		
6	5,971	5,972	5,9715	0,0007		
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8	6,014	6,018	6,0160	0,0007		
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11	6,033	6,032	6,0325	0,0007		
12	6,020	6,019	6,0195	0,0007		
13	6,007	6,007	6,0070	0,0000		
14	5,985	5,986	5,9855	0,0007		
15	6,014	6,014	6,0140	0,0000		
16	5,973	5,972	5,9725	0,0007		
17	5,997	5,996	5,9965	0,0007		
18	6,019	6,015	6,0170	0,0007		
19	5,987	5,986	5,9865	0,0007		
20	6,029	6,025	6,0270	0,0007		
21	6,017	6,019	6,0180	0,0007		
22	6,003	6,001	6,0020	0,0007		
23	6,009	6,012	6,0105	0,0007		
24	5,987	5,987	5,9870	0,0000		
25	6,006	6,003	6,0045	0,0021		

Measurement results		Statistics				
	Variance	Standard dev.	Confidence level 1 - α = 95%			
Repeatability	0.0000021600	0.0014697	EV: 0.0011526 ≤	0.0014697 ≤	0.0020288	%EV = 14.70%
R&R	0.0000021600	0.0014697	GRR: 0.0011526 ≤	0.0014697 ≤	0.0020288	%GRR = 14.70%
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Total variation	0.0003840600	0.017762	TV:	0,018		
Versuchsplan			Reference quantity			
Number of trials	=	2	Process variation	=	0	
Number of parts	=	25	Tolerance	=	0.060	
			Required Cp value	=		
Resolution			%RE =	0.0167		
Number of distinct categories (ndc)			ndc =	17		
Repeatability & Reproducibility			%GRR =	14.7%		
Minimum reference figure f. capable measur. system			T _{min} (%GRR) =	0.0882		
Min. ref. fig. f. conditionally capable measur. system			T _{min} (%GRR) =	0.0294		
Measurement system is conditionally capable (%RE, min, %GRR)						
Bosch 2018 — Procedure 3						



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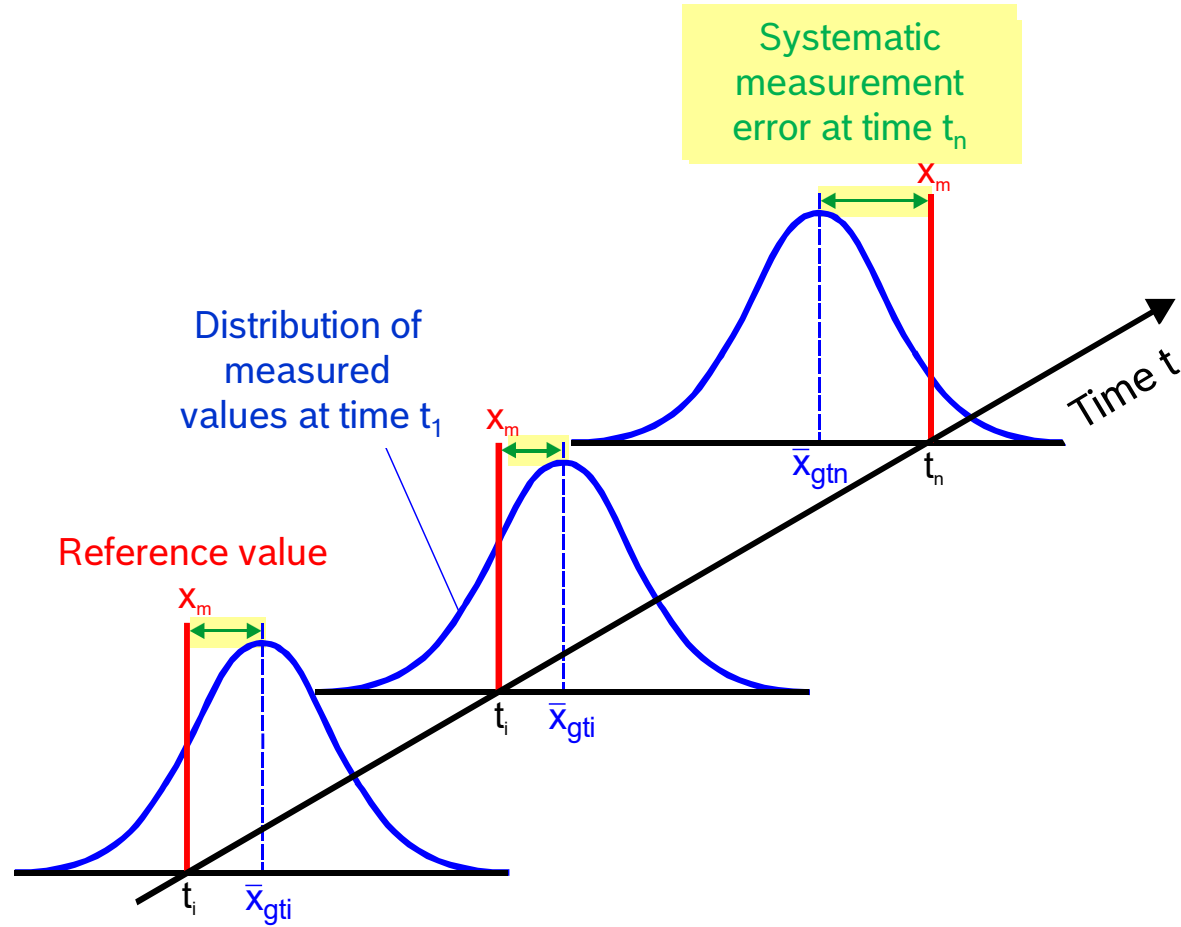
Flow chart





MSA methods acc to Bosch booklet 10

Procedure 5: stability





MSA methods acc to Bosch booklet 10

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)



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Procedure 5: stability

Conducting the study

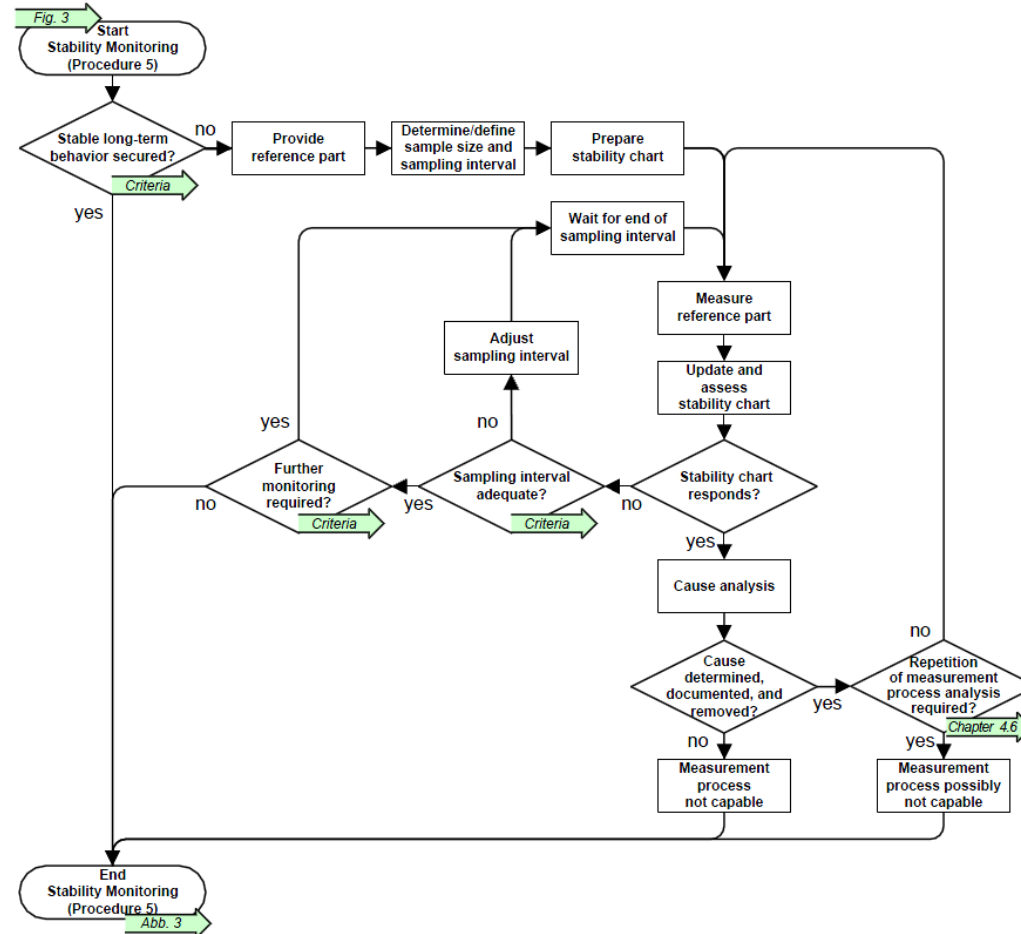
- At least three measurements ($n \geq 3$) of the reference part (stability part) are taken at regular intervals (inspection intervals, sampling intervals), as defined for the specific process.
- Document the measurement results in the data table of the stability chart.
- Calculate mean and standard 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).

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Procedure 5: stability



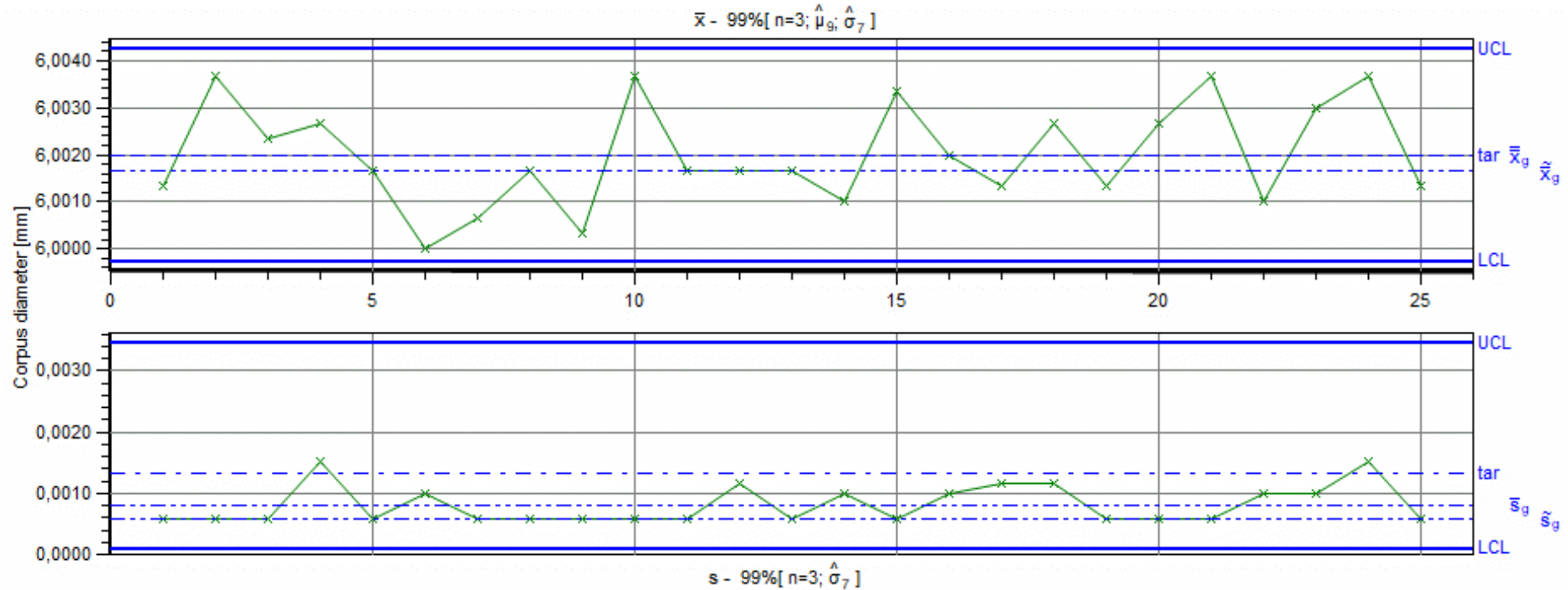
Conducting the study





MSA methods acc to Bosch booklet 10

Procedure 5: stability chart



- Calculations as for regular control charts (Bosch Booklet 7 — SPC)
- For details on general calculation of control limits see Bosch Booklet 10 Appendix F



MSA methods acc to Bosch booklet 10

Procedure 5: stability chart, control limits

	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 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 from a previous test run (see [AIAG MSA], chapter 3, paragraph B) or
- the standard deviation from procedure 1 (not recommended because of short-term study).

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

u_p , B'_{Eun} , B'_{Eob} and E'_E corresponding to the sample size n are taken from the following table for confidence level 99%. For individual value charts, it must be decided how many measured values are combined in one group of size n (pseudo-sample). $n = 3$ is well-established.

n	u_p	B'_{Eun}	B'_{Eob}	E'_E
3	2.58	0.071	2.302	2.935
4	2.58	0.155	2.069	3.023
5	2.58	0.227	1.927	3.090

99 %



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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



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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



MSA methods acc to Bosch booklet 10

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



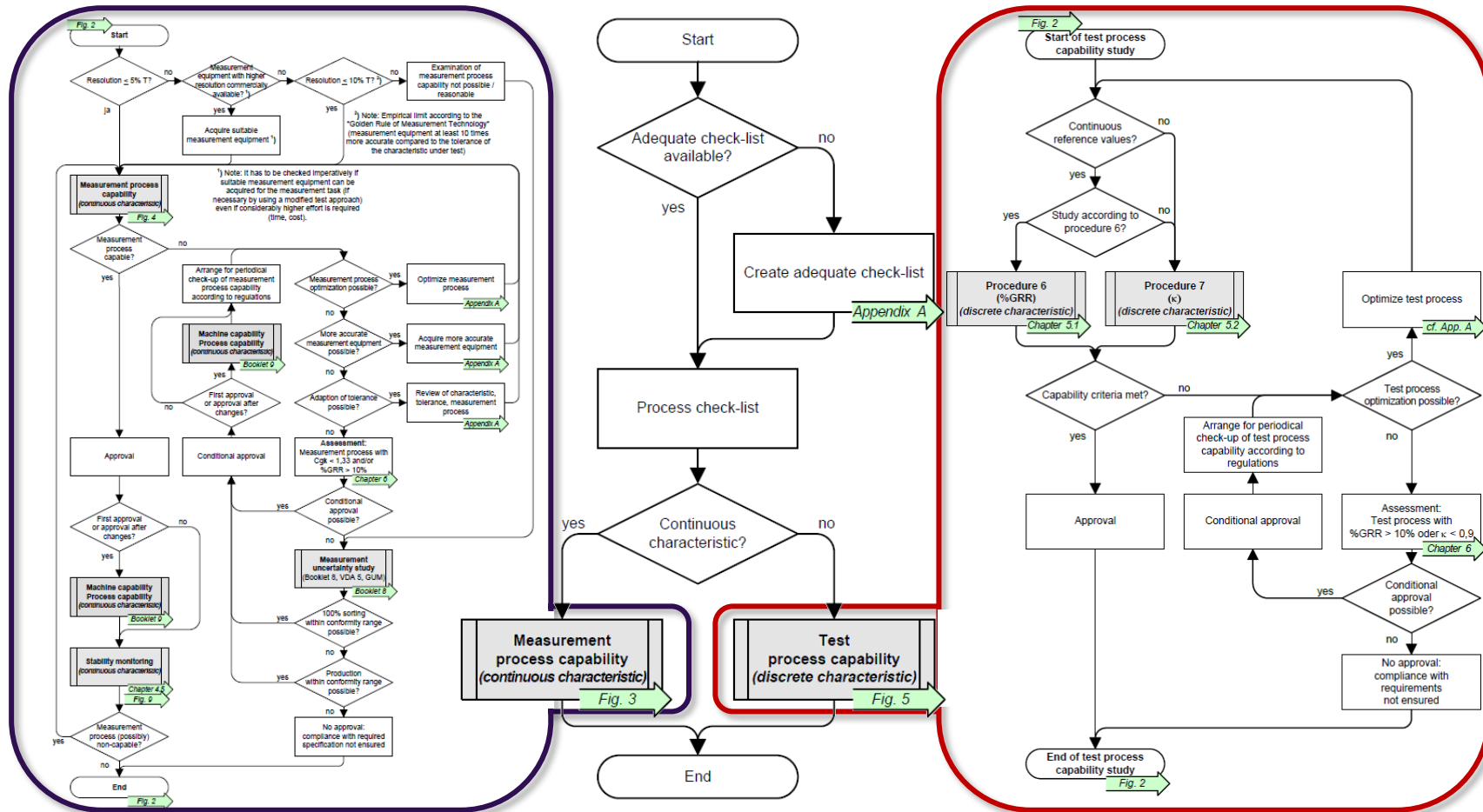
MSA methods acc to Bosch booklet 10

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
 - ...

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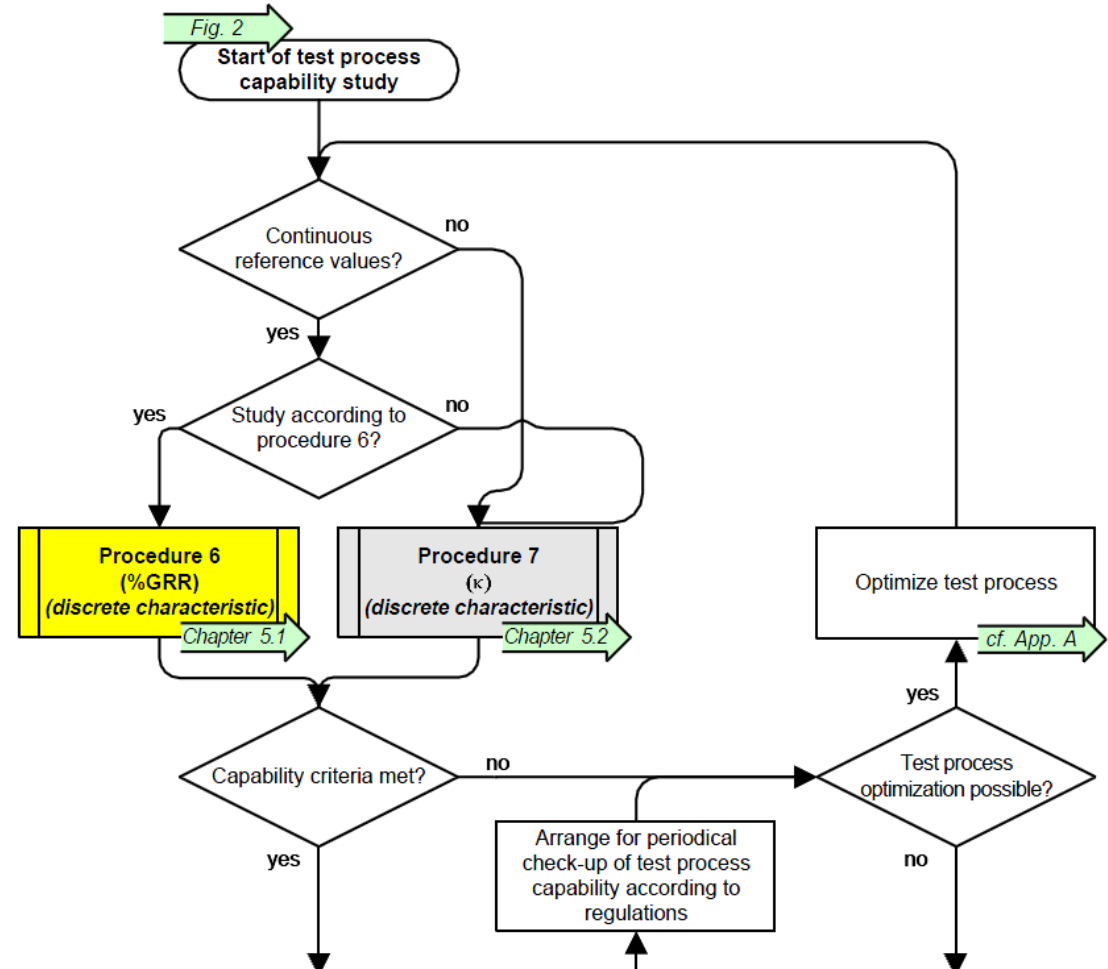
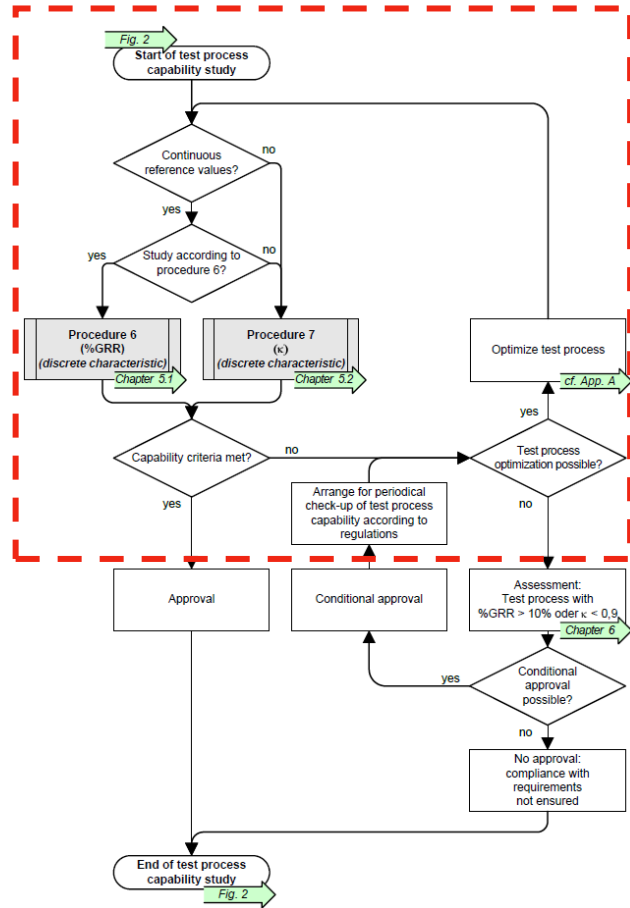
Procedures according to booklet 10





MSA methods acc to Bosch booklet 10

Flow chart

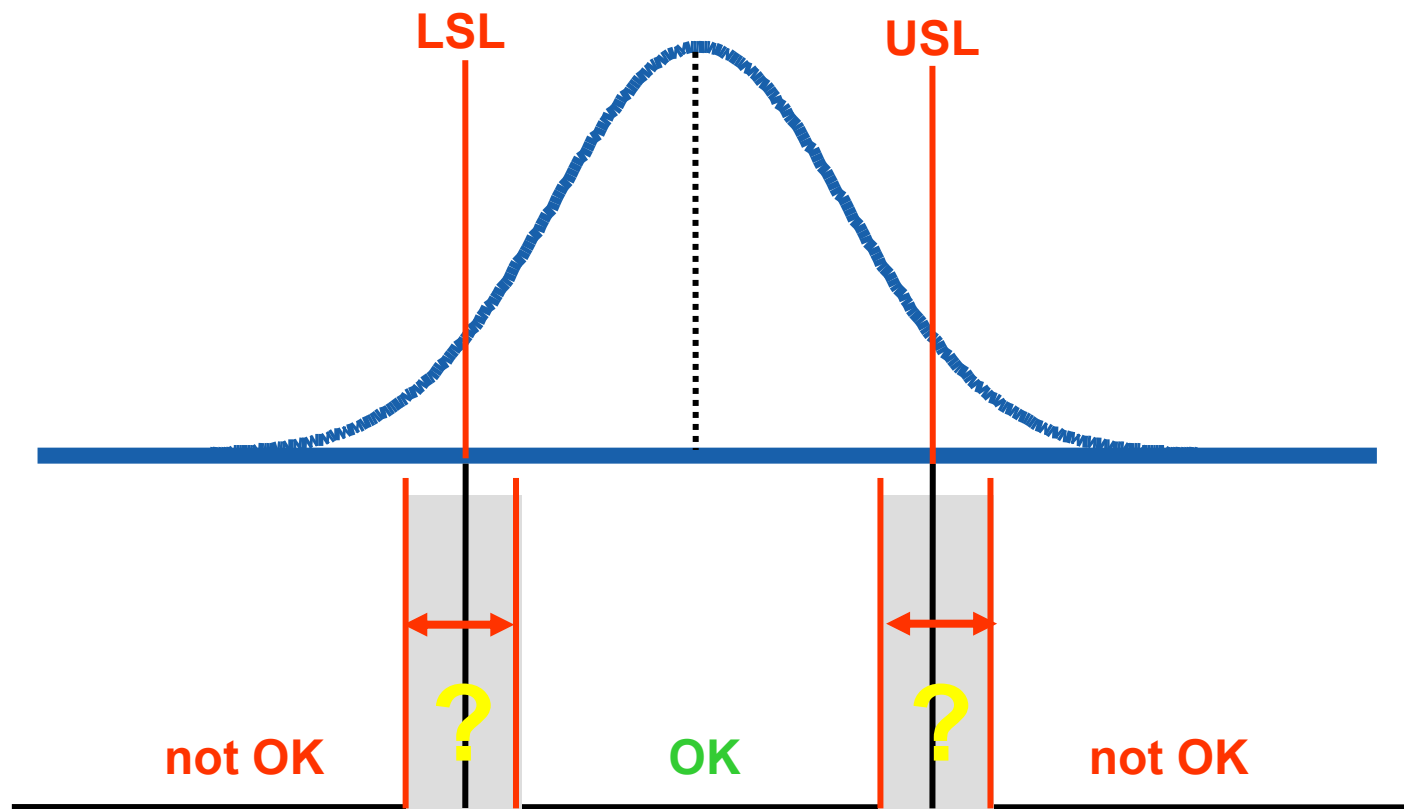




MSA methods acc to Bosch booklet 10

Procedure 6: discretized continuous characteristics

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





MSA methods acc to Bosch booklet 10

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.



TQ038 capab. of measurement. & test processes

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 3 appraisers ...
 - ... 3 times each ...
 - ... in random order.
- Enter the results in a table.

n	Ref. 1	X _{A1}	X _{A2}	X _{A3}	X _{B1}	X _{B2}	X _{B3}	
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	3,5990	⊕	⊕	☐	☐	☐	☐	⊕
50	3,6090	⊕	⊕	⊕	⊕	⊕	⊕	⊕



MSA methods acc to Bosch booklet 10

Procedure 6: discretized continuous characteristics

n	Ref. 1	X _{A1}	X _{A2}	X _{B1}	X _{B2}	
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	☒	☒	☒	☒	☒

Sort the results
in ascending order
according to the
reference value

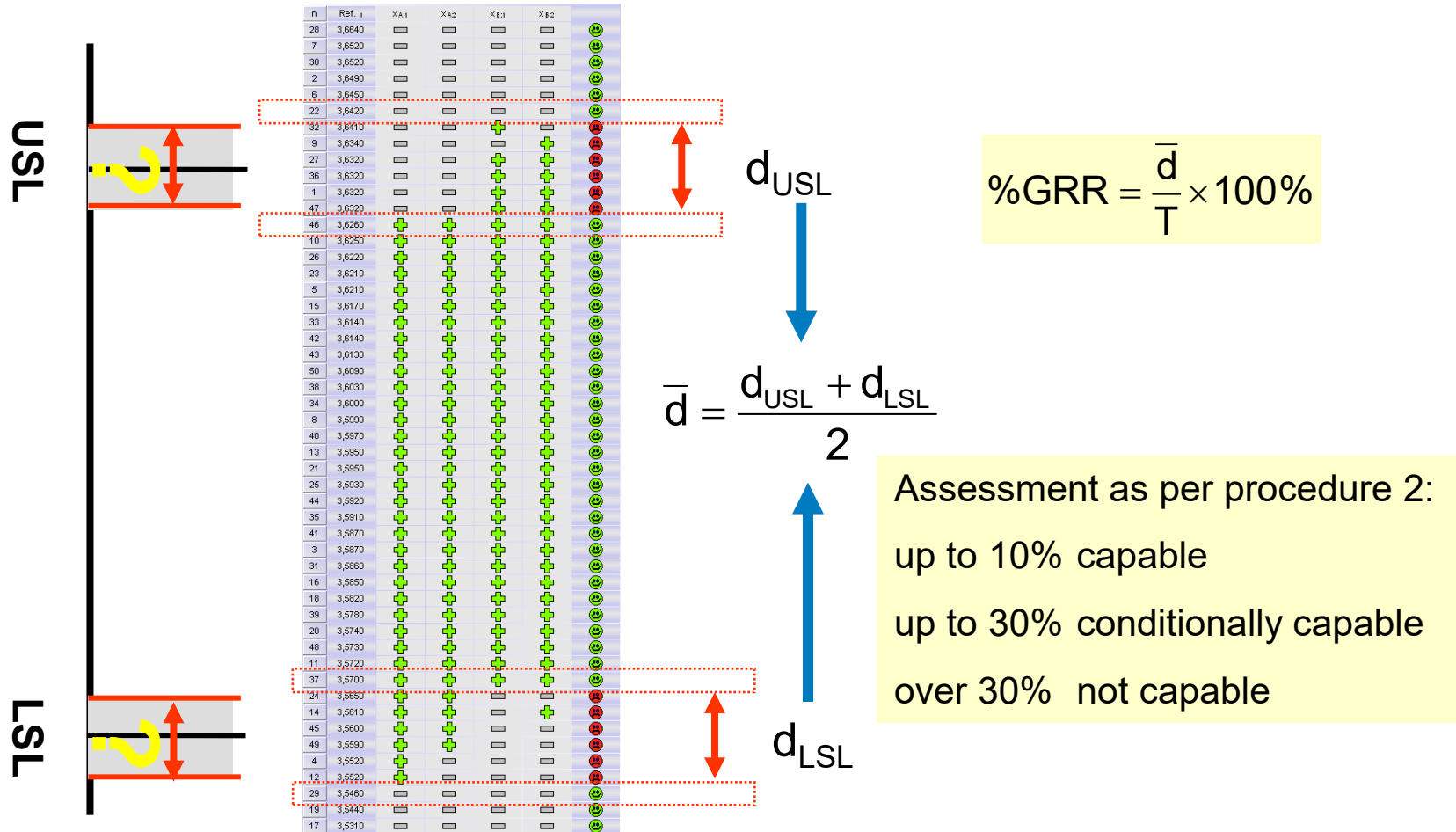


n	Ref. 1	X _{A1}	X _{A2}	X _{B1}	X _{B2}	
28	3,6640	☐	☐	☐	☐	☒
7	3,6520	☐	☐	☐	☐	☒
30	3,6520	☐	☐	☐	☐	☒
2	3,6490	☐	☐	☐	☐	☒
6	3,6450	☐	☐	☐	☐	☒
22	3,6420	☐	☐	☐	☐	☒
32	3,6410	☐	☐	☒	☐	☒
9	3,6340	☐	☐	☐	☒	☒
27	3,6320	☐	☐	☐	☒	☒
36	3,6320	☐	☐	☐	☒	☒
1	3,6320	☐	☐	☒	☒	☒
47	3,6320	☐	☐	☒	☒	☒
46	3,6260	☒	☒	☒	☒	☒
10	3,6250	☒	☒	☒	☒	☒
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	☐	☐	☐	☐	☒



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Procedure 6: discretized continuous characteristics



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Procedure 6: report



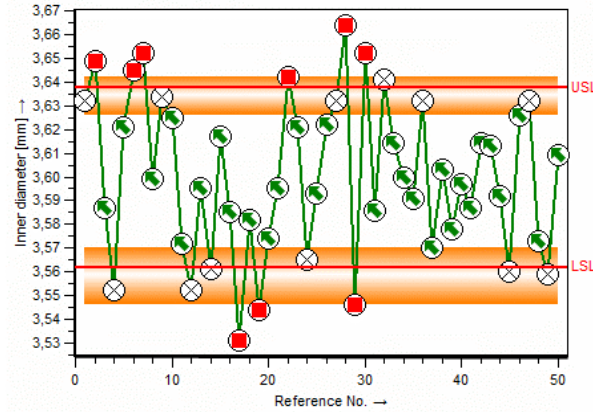
BOSCH		Measurement System Analysis Procedure 6 (Discrete Char.)		Sheet 1 / 1
Area : MSE3	Operation : Grinding inner diam.	Characteristic : Inner diameter		
Group/Dptm. : MOE7	Machine : BOKO 3	Char. No. : 1		
Workshop/sect. : W450	Machine No. : 1003954	Nominal value : 3.600		
Product : Injector	Test station : JML0782W001	Lower allowance : -0.0375		
Part : Needle	Gage : LG_4H7N1	Upper allowance : 0.0375		
Article number : 0 433 392 425	Gage No. : 67027025840013	Tolerance : 0.075		
Change status : 20.01.2019	Gage Manuf. : BaP	Unit : mm		
Resolution : 0.002				
Comment :				
Standard :	Standard No. :	Standard/Ref. value :		
1 3.6320	PA1	PA2	PA3	PA2
2 3.6490				
3 3.5870				
4 3.5520				
5 3.6210				
6 3.6450				
7 3.6320				
8 3.5990				
9 3.6340				
10 3.6220				
11 3.5720				
12 3.5520				
13 3.5950				
14 3.5610				
15 3.6170				
16 3.5850				
17 3.5210				
18 3.5820				
19 3.5440				
20 3.5740				
21 3.5650				
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 3.6000				
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				

Drawing Values	
USL	= 3,63750
LSL	= 3,56250
T	= 0,07500
Number of reference measurements	= 1
Number of reference parts	= 50
Number of appraisers	= 2
Number of trials per appraiser	= 3

Analysis of Non-Conformancies	
Number of non-conformancies	$n_{>}$ = 12
	$n_{\max>}$ = 0
	$n'_{\max>}$ = 1

Signal Detection Approach	
Non-conformance range	d_{OSG} = 0.01600
Non-conformance range	d_{USG} = 0.02400
Average non-conformance range	d = 0.02000
Repeatability & Reproducibility	%GRR = 26.67%

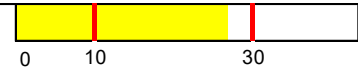
Hypothesis Tests	
Kappa _{F1}	K'_{F1} = 0.6060
Kappa _{C0}	K'_{C0} = 0.6063
Kappa _{min}	K'_{min} = ---



Drawing Values	
USL	= 3,63750
LSL	= 3,56250
T	= 0,07500
Number of reference measurements	= 1
Number of reference parts	= 50
Number of appraisers	= 2
Number of trials per appraiser	= 3

Analysis of Non-Conformancies	
Number of non-conformancies	$n_{>}$ = 12
	$n_{\max>}$ = 0
	$n'_{\max>}$ = 1

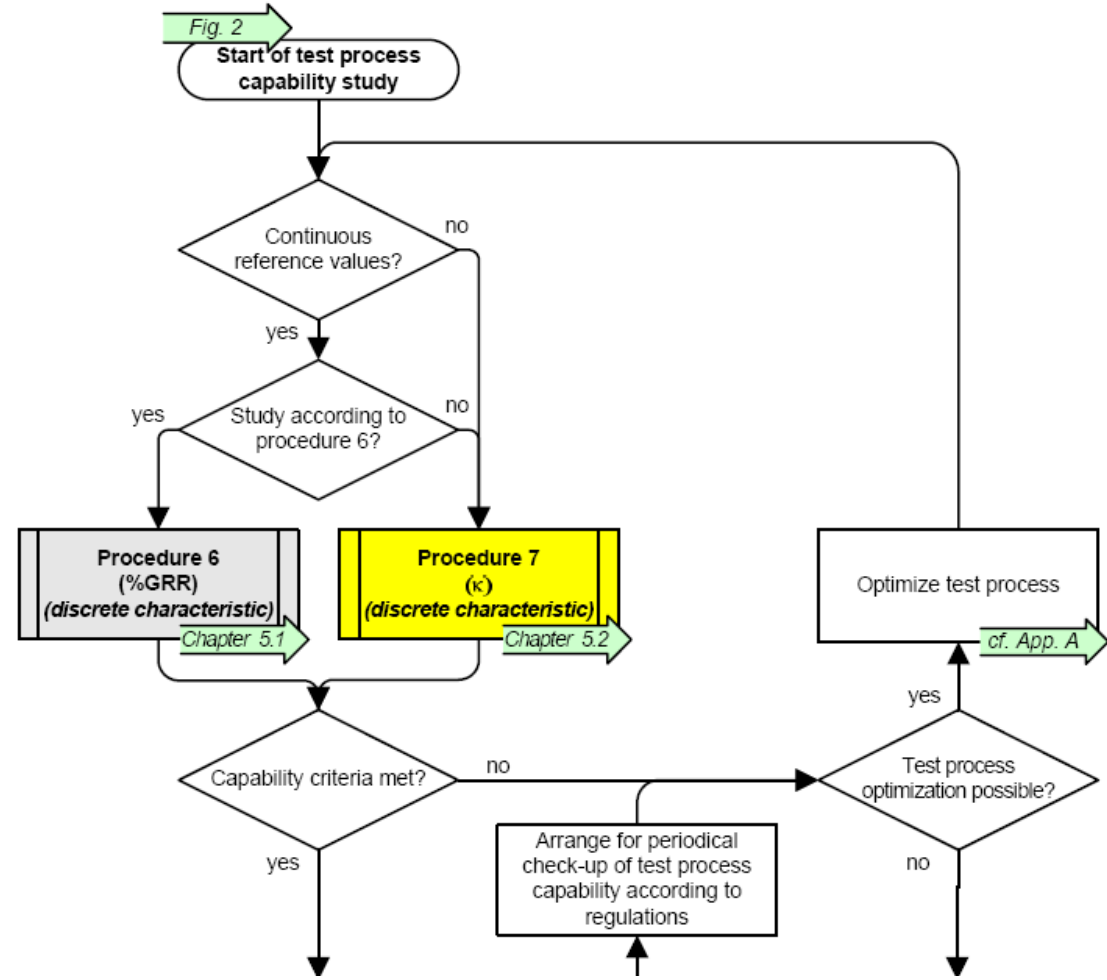
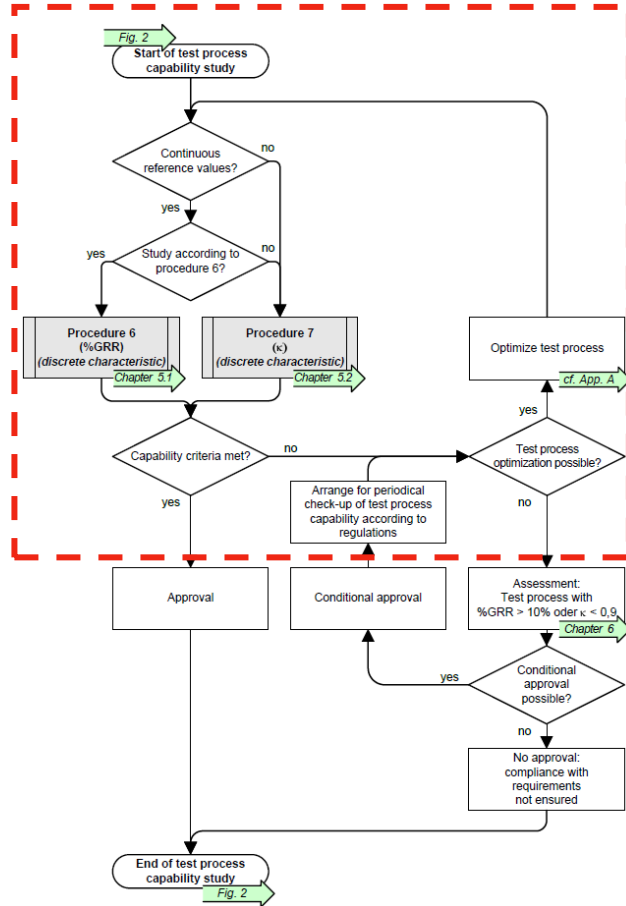
Signal Detection Approach	
Non-conformance range	d_{OSG} = 0.01600
Non-conformance range	d_{USG} = 0.02400
Average non-conformance range	d = 0.02000
Repeatability & Reproducibility	%GRR = 26.67%



Hypothesis Tests	
Kappa _{F1}	K'_{F1} = 0.6060
Kappa _{C0}	K'_{C0} = 0.6063
Kappa _{min}	K'_{min} = ---

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Flow chart





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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



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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!)



MSA methods acc to Bosch booklet 10

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 3 appraisers and 3 test runs each
- If appraiser influence is not expected: use at least 6 test runs
- Use a random inspection order, and change it for each run



MSA methods acc to Bosch booklet 10

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.



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Procedure 7: discrete characteristics

Capability Assessment

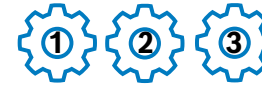
- Capability is assessed based on the κ statistic (“Kappa”):
- $\kappa \geq 0.9$: test process capable
- $0.9 > \kappa \geq 0.7$: test process conditionally capable
- $\kappa < 0.7$: test process not capable (unsuitable)
- Use the minimum of all the κ -values for the overall assessment.



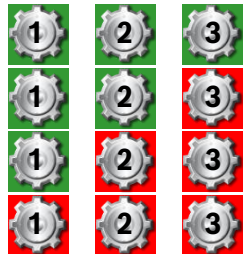
MSA methods acc to Bosch booklet 10

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
- Agreement 1-2, 2-1
- Agreement 2-3, 3-2
- Agreement 1-2, 1-3, 2-1, 2-3, 3-1, 3-2

→ $A \times A = 6$
 → $A \times A = 2$
 → $A \times A = 2$
 → $A \times A = 6$

Pairwise combinations are counted according to the same principle

- all appraisers



- each test result of each appraiser against the corresp. reference

→ $A \times B \times C = 44$
 → $A1 \times R = 0 \text{ or } 2$



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Procedure 7: discrete characteristics (analysis)

Categories:													Number of pair-wise identical combinations per test object i (i = 1, ... N ₀)										
		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	6	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	1	0	0	6	6	2	56	2	2	2	2	2	2	0	2	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	0	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



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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

Number of pair-wise identical combinations per test object i ($i = 1, \dots, N_0$)																								
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.	Reference	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
2	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	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	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	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	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	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	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	



MSA methods acc to Bosch booklet 10

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:		Number of pair-wise identical combinations per test object i (i = 1, ... N ₀)																								
Test Object No.	Referenc	Appraiser - Trial									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			
		0 - Not OK	1 - OK	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	1	6	6	6	72	2	2	2	2	2	2	2	2	2	2	2
2	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	2
3	0	0	0	0	0	0	0	0	0	0	0	6	6	6	72	2	2	2	2	2	2	2	2	2	2	2
Observed number of evaluations per category n _k (k = 1, ... N _C)				50	47	51	148	32	32	34	32	32	34	32	32	31	32	33	34							
Total number of evaluations N				100	103	99	302	68	68	66	68	68	68	68	69	68	67	66								
Observed fraction of evaluations per category n _k / N (k = 1, ... N _C)				0.3333	0.3133	0.34	0.3289	0.32	0.32	0.34	0.32	0.32	0.34	0.32	0.32	0.31	0.32	0.33	0.34							
Expected fraction of randomly identical evaluations P _{Exp} = Σ _k (n _k /N) ²				0.6667	0.6867	0.66	0.6711	0.68	0.68	0.66	0.68	0.68	0.66	0.68	0.68	0.69	0.68	0.67	0.66							
				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										



MSA methods acc to Bosch booklet 10

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” $1 - P_{Exp}$

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



MSA methods acc to Bosch booklet 10

Procedure 7: discrete characteristics (analysis)

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

		Number of pair-wise identical combinations per test object i (i = 1, ... N ₀)																						
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.	Reference	Appraiser - Trial									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	
		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
2	1	1	1	1	1	1	1	1	1	1	6	6	6	72	2	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	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	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	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	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	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 $P_{Exp} = \sum_k (n_k/N)^2$		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																						



MSA methods acc to Bosch booklet 10

Procedure 7: discrete characteristics (analysis)

- The smallest kappa value determines the overall result

		Number of pair-wise identical combinations per test object i (i = 1, ... N ₀)														
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.	Appraiser - Trial															
reference	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	(Kappa)	$\kappa \geq 0.90$ capable	$0.70 \leq \kappa < 0.90$ conditionally capable	$\kappa < 0.70$ not capable	(Kappa)	$\kappa \geq 0.90$ capable	$0.70 \leq \kappa < 0.90$ conditionally capable	$\kappa < 0.70$ 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 : <input type="checkbox"/> capable		0.70 \leq Kappa $<$ 0.90: <input checked="" type="checkbox"/> conditionally capable		Kappa $<$ 0.70: <input type="checkbox"/> not capable												

MSA methods acc to Bosch booklet 10

Procedure 7: discrete characteristics



BOSCH Quality Management		Test Process Analysis Procedure 7		BOSCH Quality Management		Test Process Analysis Procedure 7		Record No.: 9911015																																															
Product / Test Object Product: <i>Housing</i> Part: <i>Cover</i> Part / Drawing No.: <i>A 111 999 222</i> Revision: <i>05 / 02/29/2009</i>		Characteristic Designation: <i>Surface quality</i> Characteristic No.: <i>15</i> <input type="checkbox"/> Continuous Characteristic Nominal Value: <i>n/a</i> Upper Limit: <i>n/a</i> Lower Limit: <i>n/a</i> Tolerance: <i>n/a</i> Unit: <i>n/a</i> <input checked="" type="checkbox"/> Discrete Characteristic		Product / Test Object Product: <i>Housing</i> Part: <i>Cover</i> Part / Drawing No.: <i>A 111 999 222</i> Revision: <i>05 / 02/29/2009</i>		Characteristic Designation: <i>Surface quality</i> Characteristic No.: <i>15</i> <input type="checkbox"/> Continuous Characteristic Nominal Value: <i>n/a</i> Upper Limit: <i>n/a</i> Lower Limit: <i>n/a</i> Tolerance: <i>n/a</i> Unit: <i>n/a</i> <input checked="" type="checkbox"/> Discrete Characteristic		Measuring & Test Equipment Location: <i>XxPW000999</i> Test / Measuring Station: <i>Visual inspection</i> Test / Measuring Equipment No.: <i>123 456 789</i> Designation: <i>Boundary samples catalogue</i> Calibration Certificate No.: <i>n/a</i> Measurement Uncertainty: <i>n/a</i>		Sheet <i>1</i> of <i>2</i>																																													
Test Method: <i>Visual inspection, manually, room temperature 20.2°C, light inten</i>																																																							
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 $0 - \text{Not OK}$ $1 - \text{OK}$																																																			
Test Data: <i>See sheet 2 ff</i>																																																							
Analysis <table border="1" style="width:100%; border-collapse: collapse;"> <thead> <tr> <th rowspan="2">Appraiser name</th> <th rowspan="2">Symbol</th> <th colspan="4">Within appraiser without reference</th> <th rowspan="2">K_A</th> </tr> <tr> <th>κ (Kappa)</th> <th>$\kappa \geq 0.90$ capable</th> <th>$0.70 \leq \kappa < 0.90$ conditionally capable</th> <th>$\kappa < 0.70$ not capable</th> </tr> </thead> <tbody> <tr> <td><i>Miller</i></td> <td><i>A</i></td> <td><i>0.7600</i></td> <td></td> <td><i>X</i></td> <td></td> <td><i>0.8</i></td> </tr> <tr> <td><i>Smith</i></td> <td><i>B</i></td> <td><i>0.8451</i></td> <td></td> <td><i>X</i></td> <td></td> <td><i>0.9</i></td> </tr> <tr> <td><i>King</i></td> <td><i>C</i></td> <td><i>0.7029</i></td> <td></td> <td><i>X</i></td> <td></td> <td><i>0.7</i></td> </tr> <tr> <td colspan="7" style="text-align: center;">Between appraisers without reference</td> </tr> <tr> <td><i>all</i></td> <td></td> <td><i>0.7336</i></td> <td></td> <td><i>X</i></td> <td></td> <td><i>0.8</i></td> </tr> </tbody> </table>										Appraiser name	Symbol	Within appraiser without reference				K _A	κ (Kappa)	$\kappa \geq 0.90$ capable	$0.70 \leq \kappa < 0.90$ conditionally capable	$\kappa < 0.70$ not capable	<i>Miller</i>	<i>A</i>	<i>0.7600</i>		<i>X</i>		<i>0.8</i>	<i>Smith</i>	<i>B</i>	<i>0.8451</i>		<i>X</i>		<i>0.9</i>	<i>King</i>	<i>C</i>	<i>0.7029</i>		<i>X</i>		<i>0.7</i>	Between appraisers without reference							<i>all</i>		<i>0.7336</i>		<i>X</i>		<i>0.8</i>
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Test Data: <i>See sheet 2 ff</i>																																																							
Analysis																																																							



MSA methods acc to Bosch booklet 10






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 a 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

04

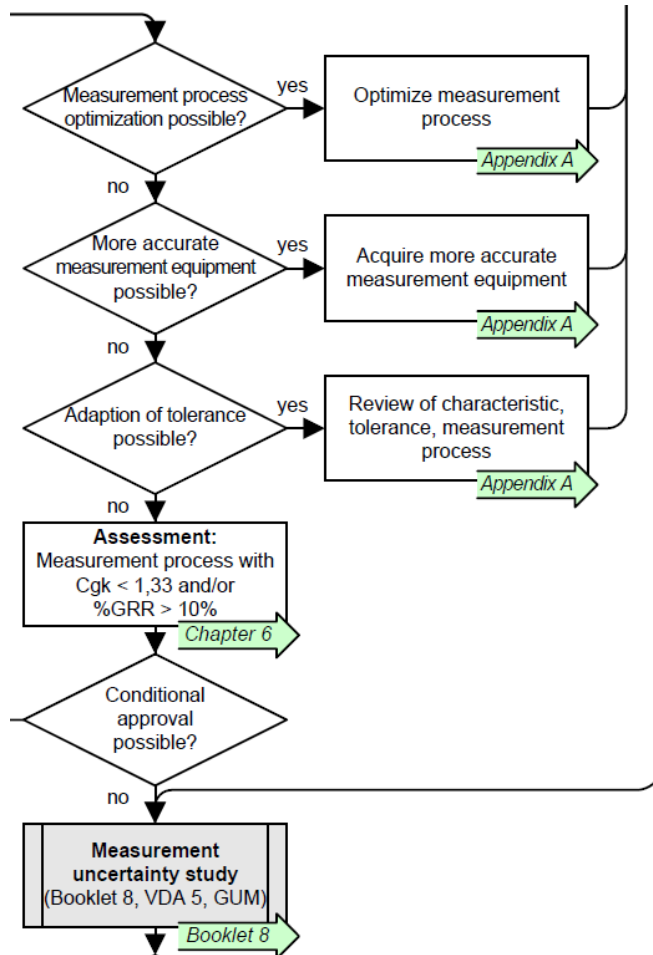
Assessment of non-capable processes and approval decision

04

-  Introduction
-  Definitions and requirements from standards
-  MSA methods acc to Bosch booklet 10
-  **Assessment of non-capable processes and approval decision**
-  Causes of non-capable measurement systems

Assessment of non-capable measurement and test processes

Non-capable measurement or test processes



Observe sequence in Booklet 10:

- 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

Assessment of non-capable measurement and test processes

Non-capable measurement or test processes



BOSCH Quality Management	Assessment of Non-capable Measurement & Test Processes	Record No.: 9911015
		Sheet 1 of 2
Measuring Equipment	Characteristic	Measurement Standard

Location: W01
 Designation: Me
 Equipment No.: LX
 Resolution: 0.0

1. Capability indices of procedures 1 – 4 and 6 – 7

Check the applicable result for each procedure (n/a – procedure not applicable / not used)

1. Capability indices

Check the applicable n/a

Pro-cedure	n/a	capable
1		
2		
3	X	
4		X
4 (MSA)	X	
5	X	
6	X	
7	X	

Key figure 1

Highest key figure achieved

Pro-cedure	n/a	capable	conditionally capable		not capable	
1			$1.20 \leq C_{gk} < 1.33$	X	$0.80 \leq C_{gk} < 1.20$	$C_{gk} < 0.80$
2			$10\% < \%GRR \leq 20\%$		$20\% < \%GRR \leq 30\%$	X $\%GRR > 30\%$
3	X		$10\% < \%GRR \leq 20\%$		$20\% < \%GRR \leq 30\%$	$\%GRR > 30\%$
4		X	$1.20 \leq \text{MIN}(C_{gk}) < 1.33$		$0.80 \leq \text{MIN}(C_{gk}) < 1.20$	$\text{MIN}(C_{gk}) < 0.80$
4 (MSA)	X		conditionally capable		not capable	
5	X		conditionally capable		not capable	
6	X		$10\% < \%GRR \leq 20\%$		$20\% < \%GRR \leq 30\%$	$\%GRR > 30\%$
7	X		$0.8 \leq K < 0.9$		$0.7 \leq K < 0.8$	$K < 0.7$
Key figure 1			1		2	X 7

Highest key figure achieved is relevant

2. External relevancy

Evaluation according to

Consequences for client

B-assessment according to FMEA

Key figure 2

Description of failure implication

3. Internal relevancy

Evaluation according to

Consequences for Bosch

B-assessment according to FMEA

Key figure 3

Description of failure implication

1	2	3	7
		X	

Outer diameter is too large, component group must be scrapped, increased failure costs

Assessment of non-capable measurement and test processes

Non-capable measurement or test processes



BOSCH Quality Management	Assessment of Non-capable	Record No.: 9911015																																																								
	Measuring Equipment Location: W025 Designation: Measurement Equipment No.: LX 0815 P1 Resolution: 0.001 mm	<h3>2. External relevance of failures (implication for customer)</h3> <p>Evaluation according to design and process FMEA (see booklet 14; CDQ0305; divisional & plant specific regulations)</p> <table border="1"> <tr> <td> Consequences for client </td> <td> none </td> <td> insignificant to marginal </td> <td> moderately serious to serious </td> <td> very serious </td> </tr> <tr> <td> B-assessment according to FMEA </td> <td>1</td> <td>2 - 4</td> <td>5 - 8</td> <td>9 - 10</td> </tr> <tr> <td> Key figure 2 </td> <td>1</td> <td>2</td> <td>3</td> <td>7</td> </tr> <tr> <td> Description of failure implication </td> <td colspan="4"> Outer diameter is too large, component group cannot be used in the vehicle; 0 km complaint </td> </tr> </table>		Consequences for client	none	insignificant to marginal	moderately serious to serious	very serious	B-assessment according to FMEA	1	2 - 4	5 - 8	9 - 10	Key figure 2	1	2	3	7	Description of failure implication	Outer diameter is too large, component group cannot be used in the vehicle; 0 km complaint																																						
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Assessment of non-capable measurement and test processes

Non-capable measurement or test processes



BOSCH Quality Management	Assessment of Non-capable Measurement & Test Processes	Record No.: _____
Measuring Equipment Location: W025 Designation: Measurement sensor Equipment No.: LX 0815 P1 Resolution: 0.001 mm	Characteristic Measuring / Test Object: Shaft Drawing No.: 1460320000 Designation of Characteristic: Outer diameter Normal Value: 6.000 mm Tolerance: 0.060 mm	Measurement S Designation: P Equipment No.: L Reference Value: 6 Uncertainty U ₉₅ : 0

BOSCH Quality Management	Assessment of Non-capable Measurement & Test Processes	Record No.: 9911015
		Sheet 2 of 2

4. Result of assessment and measures

Product of key figures: $\frac{2}{\text{Key figure 1}} \times \frac{3}{\text{Key figure 2}} \times \frac{3}{\text{Key figure 3}} = \frac{18}{\text{Key figure of assessment}}$

Result	Decision	Measures	Responsible	Due Date
1 - 2	Conditional release Periodical check-up for possible process improvement.	Optimize measuring system (prevent from manual influence) Repeat MSA according to procedure 1	Mr. ABC Mr. ABC	10/30/2009 10/30/2009
3 - 6	Conditional release Periodical check-up for possible process improvement. Proof of effectiveness of the measures in order to avoid failure effects (customer complaints).	Optimize measuring system (prevent from manual influence) Repeat MSA according to procedure 1 Safeguard characteristic by additional test XXX ...	Mr. ABC Mr. ABC Mr. DEF	10/30/2009 10/30/2009 11/30/2009
≥ 7	No release The functionality of the characteristic must be ensured by means of a capable indirect test. If external failure implications cannot be ruled out, arrangements are established together with the development department which is in charge for the product. The customer has to be informed.	Define a new measuring method ... Acquire more precise measurement equipment ... Repeat MSA according to procedure ... Safeguard characteristic by additional test XXX ...	Mr. ABC Ms. XYZ Mr. DEF Mr. DEF	10/30/2009 11/30/2009 12/10/2009 10/1/2009

5. Approval (according to in-plant directives)

Person in charge	Date: 9/15/2009	Department: XyPW025	Name: Amann	Signature: <i>Amann</i>
Head of department: Production	Date: 9/16/2009	Department: XyP/MOE	Name: Bemann	Signature: <i>Bemann</i>
Head of department: Quality management	Date: 9/17/2009	Department: XyP/QMM	Name: Cefrau	Signature: <i>Cefrau</i>
Head of department: Development	Date: 9/18/2009	Department: GB/EXY	Name: Demann	Signature: <i>Demann</i>

1. Capability indices of procedures 1 – 4 and 6 – 7

Check the applicable result for each procedure (N/A – procedure not applicable / not used)

Pre-conditions	1/A	2/A	3/A	4/A	6/A	7/A
1						
2						
3	X					
4		X				
4 (MSA)	X					
5	X					
6	X					
7	X					
Key figure 1						

2. External relevance of failures (implication for customer)

Evaluation according to design and process FMEA (see booklet 14, CDG0305, divisional & plant specific regulation)

Consequences for client	none	insignificant to marginal	moderately serious to serious
B-assessment according to FMEA	1	2 - 4	5 - 8
Key figure 2	1	2	3
Description of failure implication	Outer diameter is too large, component group cannot be used in the veh 0 km complaint		

3. Internal relevance of failures (implication for Bosch)






Evaluation according to design and process FMEA (see booklet 14, CDG0305, divisional & plant specific regulation)

Consequences for Bosch	none	insignificant to marginal	moderately serious to serious
B-assessment according to FMEA	1	2 - 4	5 - 8
Key figure 3	1	2	3
Description of failure implication	Outer diameter is too large, component group must be scrapped, increa.		

05

Causes of non-capable measurement systems

05

-  Introduction
-  Definitions and requirements from standards
-  MSA methods acc to Bosch booklet 10
-  Assessment of non-capable processes and approval decision
-  **Causes of non-capable measurement systems**



Causes of non-capable measurement systems

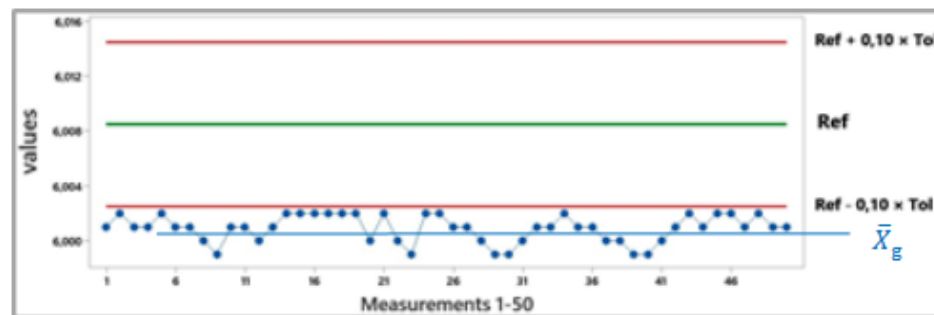
Non-capable measurement or test processes

Systematic offset (relevant for procedure 1):

A systematic offset means there is a gap between the specified reference-value and the mean measured value of the reference part.

Possible causes could be:

- Check the calibration of your measurement system – compensate a systematic offset
- Check setup/ filter of the measurement system
- Has the reference part picked out correctly. Is it undamaged and ok?
- Is there some kind of mechanical offset due to damage or mal-adjustment?



Same measurement position on the part has to be ensured for all measurements
(stable condition of master part)

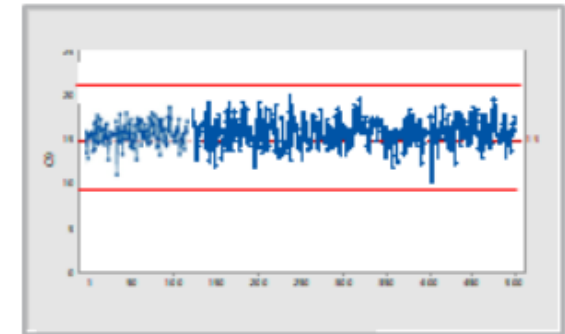


Causes of non-capable measurement systems

Non-capable measurement or test processes

Possible causes for a random variance of the measurements:

- **Parts variance in MSA study:** unstable measuring position vs. unstable characteristic (e.g., diameter influenced by roundness dev.) => assure same measuring position in each run (position marks, check the fixture / stabilize positioning) or assure stable characteristic
- **Instable part:** Characteristic not stably measurable; Characteristic deforms during measurement e.g., rubber parts or filigree parts → choose an alternative measurement position (more stable geometry element), reduce measuring forces (increase contact surface between part and device), use a reference part of stable material
- **Clamping influence:** Check deformation of the parts during positioning → Adjust clamping concept, pressure and/or position
- Eliminate **disturbances** as vibrations, draughts, contamination, etc.



Relevant for procedure 1, 2, 3, 4, 5.

If the causes have been eliminated for procedure 1 -> not expected during performing other procedure.



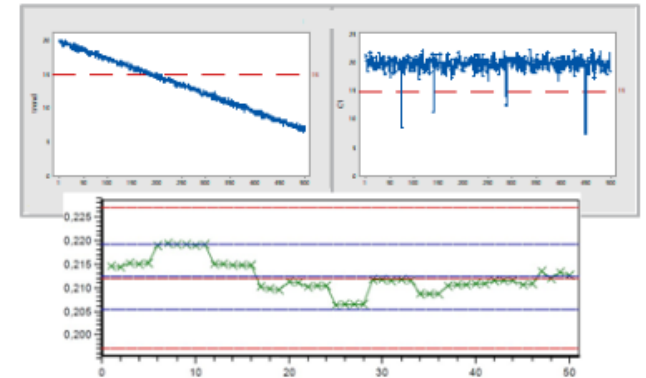
Causes of non-capable measurement systems

Non-capable measurement or test processes

Possible causes for a non-random variance: (Outlier, shift, temp. offset):

Important: Identify if the variation is due to the parts or to the IMT equipment!

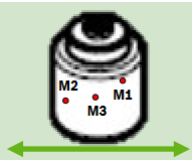
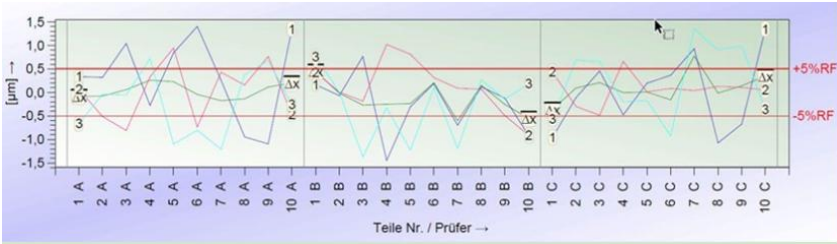

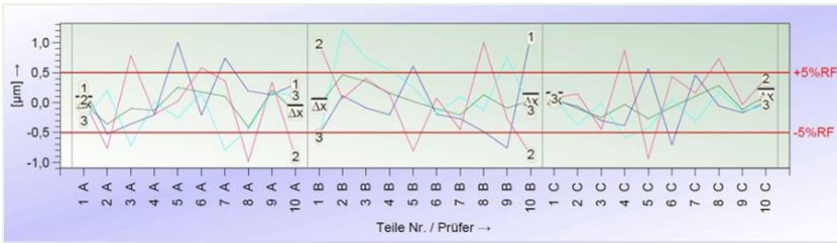

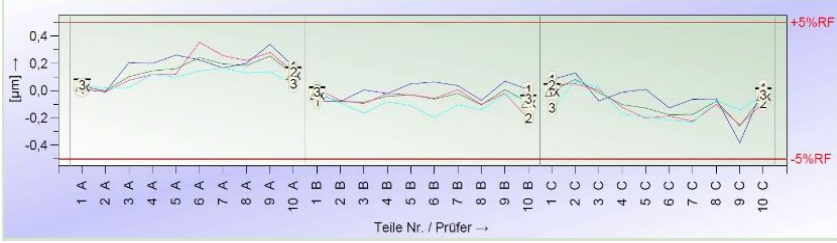
- Parts are not fixed correctly (e.g. clamping force, orientation etc), not ensuring the repeated measurement position on the part
- Variance changes / shifts over time (continuously or suddenly) -> e.g., Temperature effect, changes in the measuring conditions
- Stable measurement conditions of the part ensured -> e.g., Humidity for conditioning of plastic parts
- Eliminate disturbances as vibrations, draughts, contamination, etc.



Causes of non-capable measurement systems

Non-capable measurement or test processes: example

Sliding coating thickness on sleeve (1/2)

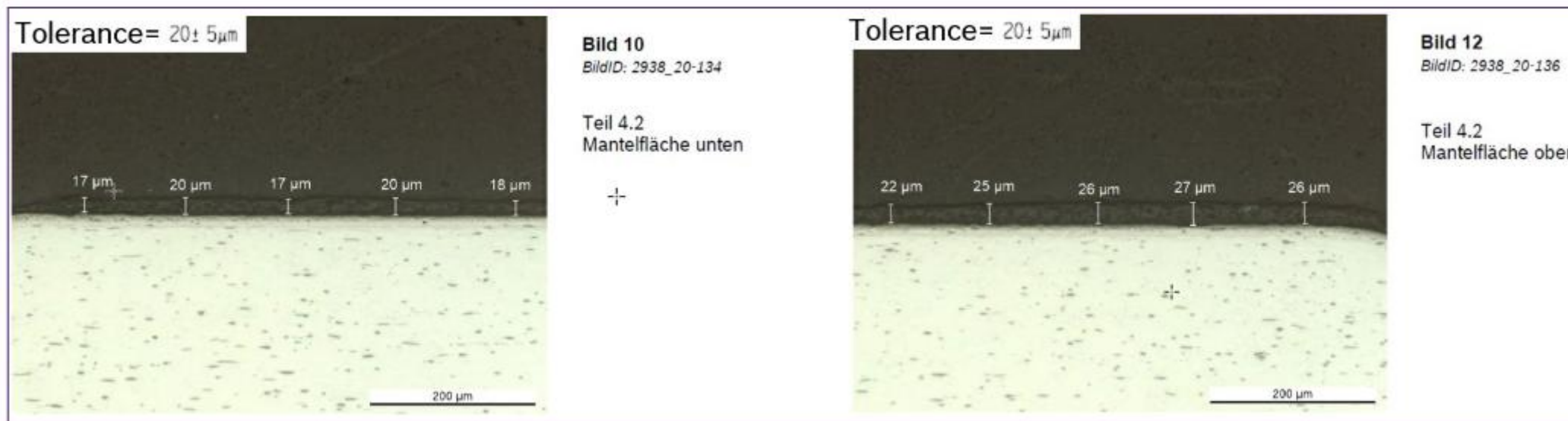
Trial	Measurement variation	%GRR	Findings and Actions
Random measurement position in repetitions M1-M3 		44%	Non-capable process with high variation -> exclude parts variation in MSA study by repeating exact position for measurement runs
Repeated measurement position with new clamping 		32%	Reduction of variance by 27% - still non-capable -> trial runs without new clamping to analyze clamping influence
Repeated measurement position without new clamping 		9,95%	Reduction of variance by 77% - GRR capable -> clamping has high influence on result/variation -> analyze coating homogeneity in cut to understand



Causes of non-capable measurement systems

Non-capable measurement or test processes: example

Sliding coating thickness on sleeve (2/2)



- Extremely instable coating thickness: in 0,6mm area, coating thickness variation by 50% of the tolerance
- Measurement strategy and tolerance not suitable for coating distribution
- Redefine area specific coating thickness and define measurement procedure as mean of 3 – 5 measurements of defined measurement position

THANK YOU!

