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Comparison of Capability Analyses for Measurement Processes according to VDA Volume 5 and MSA

History

Who is not familiar with the famous statement about the art of measuring: "The one who measures measures crap". The most crucial question for any type of measurement is about accuracy and precision. The first procedure ensuring measurement accuracy was developed in ancient Egypt. As early as 2500 B.C. they carved a "royal cubit master" out of a block of granite to measure the water level of the Nile and to gain comparable results. On a visit to Paris, you should also keep your eyes peeled for the marble metre bar. You may find two of these 18th century material measures on house walls. The Parisian population, especially merchants, compared the length of their measuring sticks to these marble metres. This was also the time when the first provisional metre bar was constructed. Only a few years later, the first mètre des archives platinum bar standard was also produced there; it was finally replaced by a platinum-iridium bar another 100 years later. In 1960, the prototype metre was defined by the wavelength of light from a specified transition in krypton-86 in vacuum and in 1983; the metre became the length of the path travelled by light in vacuum during a specified time interval. All these changes did not always intend to provide a new definition of the size of a metre but tried to increase its precision.

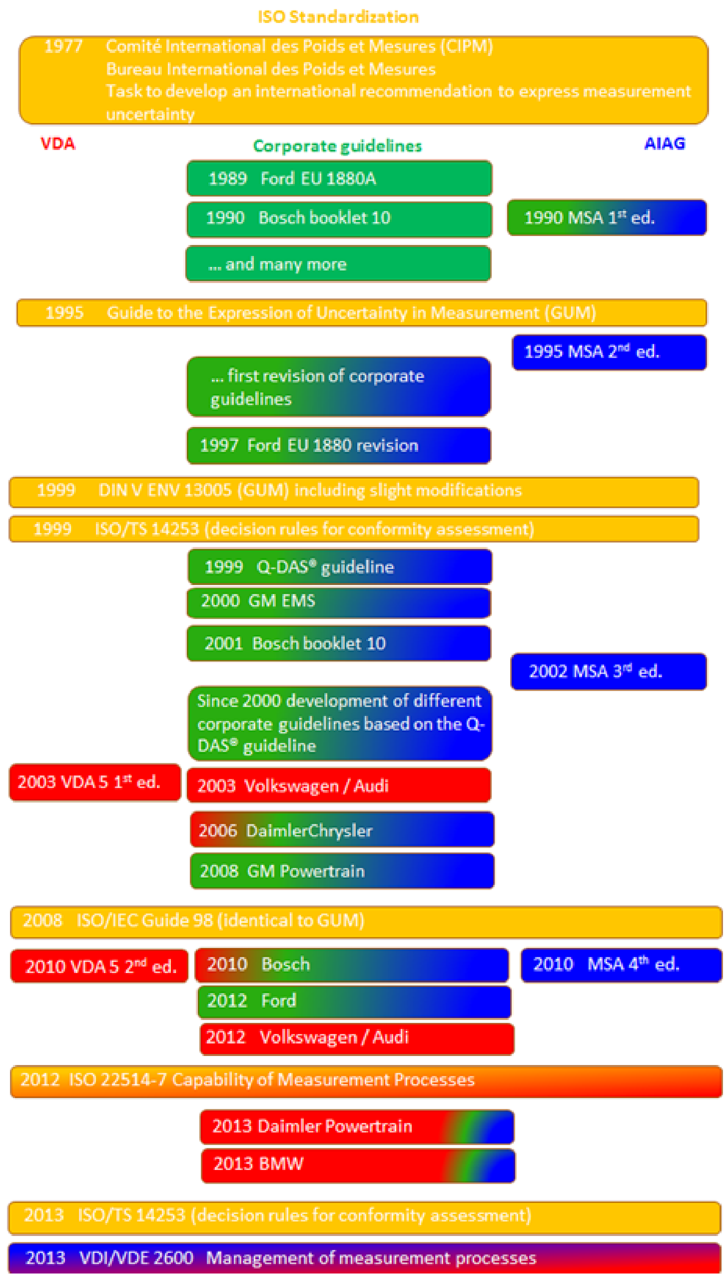

Figure 1: Development of measurement uncertainty and measurement systems analysis over time

GUM - Guide to the expression of uncertainty in measurement

It is even more surprising that the SI system has not had any uniform rules as to measurement "accuracy" yet at the time when the length of the metre was defined – a length that we still apply today. Even though the international Committee for Weights and Measures (CIPM) had already requested a recommendation on the calculation of measurement uncertainty from the international Bureau of Weights and Measures (BIPM), ISO was not entrusted with preparing a detailed guideline until 1986. The “Guide to the expression of uncertainty in measurement“ (GUM) based on the BIPM recommendation was published in 1995.

The beginnings of measurement system analysis

At that time, the automotive industry also tried to introduce SPC in production, including the operator self-inspection as is common practice today. SPC measuring stations close to the machines were provided with various measuring instruments in order that operators are able to take required measurements directly. However, the automotive industry hardly considered the question at all whether the respective measuring instruments were able to fulfil the corresponding measuring task with sufficient accuracy. However, they soon had to realise that not only the manufacturing process itself caused the observed variations but even the measurement process led to variations that were not to be underestimated. In many cases, the variation caused by the measurement process was even greater than the variation caused by the manufacturing process. At least by now, it was time to deal with the topic of capability analysis of measurement and test processes. However, the automotive industry did not focus on a detailed analytical assessment of measurement uncertainty but gave priority to a general assessment defining whether a measurement process is suitable for a specific application. As an example, Ford created a thin booklet in 1989 recommending the application of a two-step procedure to inspect the measurement process. The first step was to take fifty measurements from a reference part and to evaluate the random and systematic errors according to the SPC methods based on C_g and C_{gk}. After the first step was taken, three operators measured each of 10 parts three times helping to evaluate repeatability and reproducibility based on %R&R (referred to as %GRR today) in the respective situation. Still today, these two procedures are called ”type-1 study“ and ”type-2 study“.

AIAG reference manual ”Measurement Systems Analysis“

The Automotive Industry Action Group AIAG was right to realise that the development of numerous different guidelines was undesirable in the automotive industry and published the “Measurement Systems Analysis“ manual in 1990. Unfortunately, it did not include all the methods given in the various corporate guidelines. This is the reason why the “Big Three“ (Ford, GM, Chrysler) in fact had a common industry standard but continued to develop their own detailed corporate guidelines. In 1995, the AIAG MSA quickly gained in importance when it became the reference manual within the scope of QM system certification according to QS 9000. Still today, it is known as AIAG Core Tool and MSA serves as a reference manual to ISO/TS 16949. In this respect, the AIAG MSA manual is the most widespread document referenced with regard to this topic, at least from a worldwide perspective.

Figure 2: MSA now and then

AIAG MSA and corporate guidelines

Nowadays, the 4^{th} edition of the AIAG MSA applies. The first two chapters of this book are rather a kind of “textbook“ discussing measurement basics and presenting different aspects of capability analyses. Chapter 3 already recommends specific methods for measurement system and measurement process capability analyses. However, the AIAG MSA gives ample scope for the execution of tests and interpretation of results. Moreover, it still does not support “type-1 studies”, a procedure included in each and every corporate guideline. Until today, a reasonable harmonization of its contents has not taken place. However, the corporate guidelines for capability analyses have been a subject of continuous adaptations and developments. In German-speaking countries, Bosch booklet 10 “Capability of Measurement and Test Processes“ is the best known document.

How the standardisation of capability analysis developed

Standardisation committees simultaneously continued to analyse the aspect of measurement uncertainty and implemented it in standards. As an example, any calibration laboratory has to assess the expanded measurement uncertainty according to GUM to become ISO/IEC 17025 accredited. This rule applies to any unit a laboratory uses to calibrate measuring instruments. For the acceptance of coordinate measuring machines, you have to meet the requirements of standards such as ISO 15530 or VDI/VDE 2617 sheet 8 demanding the proof of measurement uncertainty. The evaluation of measurement uncertainty is even relevant within the scope of product liability. And for conformity assessments based on ISO 14253-1, you have to consider the measurement uncertainty at the tolerance limits. The “Guide to the expression of uncertainty in measurement“ (GUM), however, did not define any specific method but only provided the basic conditions the calculation of uncertainty required. According to this guide “it may therefore be necessary to develop particular standards based on this Guide that deal [...] with the various uses [...].“ What follows is: “Although this Guide provides a framework for assessing uncertainty, it cannot substitute for critical thinking, intellectual honesty and professional skill.” GUM also refuses any evaluation of measurement uncertainty. Its only purpose is the objective expression of measurement uncertainty; it does not provide any kind of capability analysis for a specific application.

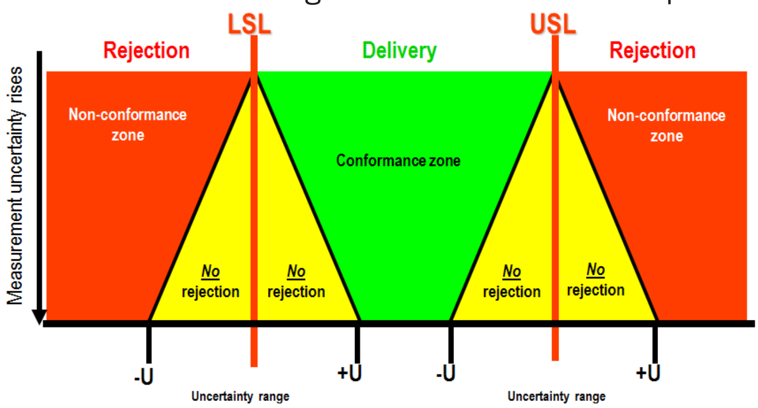

Figure 3: ISO 14253-1 requirements

Approach according to AIAG MSA

On the other hand, AIAG’s MSA reference manual refuses to express measurement uncertainty, especially for reasons of complexity. It only examines and evaluates known critical components of variation, such as bias, repeatability and reproducibility, linearity and stability over time in a real application in order to ensure that the measurement system can be used in a SPC environment. It even applies a version of the well-known “one-tenth rule” in this example. The variation of the measurement system is likely to increase the observed process variation. Since you always add the square of the component of variation (variances), an additional variation of 10% leads to an increase of the total variation by less than 1%. This is the reason why a measurement system with a variation of %GRR ≤ 10% is supposed to be acceptable. With a maximum %GRR = 30%, a measurement process is considered to be conditionally capable and you

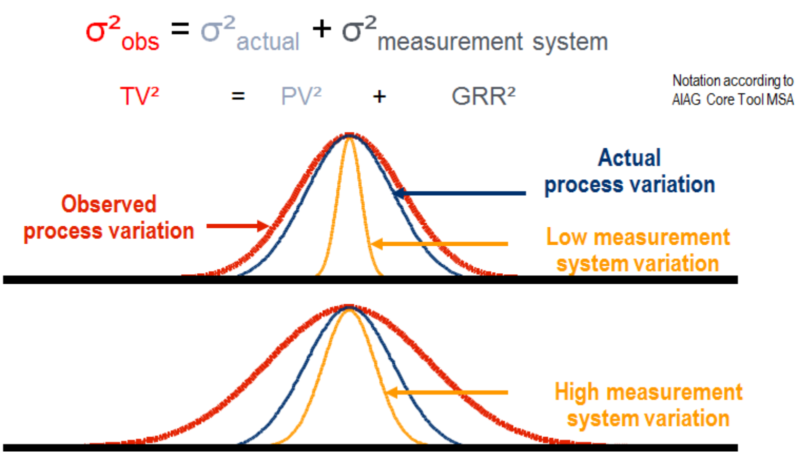

Figure 4: Background of the AIAG MSA manual and the “one-tenth rule”

might still release these measurement processes depending on the respective process risk. A detailed analysis is thus not required and the examined components of variation were thus not referred to as uncertainties. Due to defined conditions, critical uncertainty components such as resolution RE and calibration uncertainty U_{cal} are assumed to be negligible. AIAG's MSA manual does not consider uncertainty components from the environment or test part but especially tries to keep these influences constant in process acceptance. Environmental influences only become relevant in stability analyses.

The user's dilemma

The user is now caught between the devil and the deep blue seas.

- Serial measurement processes in a SPC environment only need a capability analysis.
- The measurement uncertainty has to be known in conformity assessments.

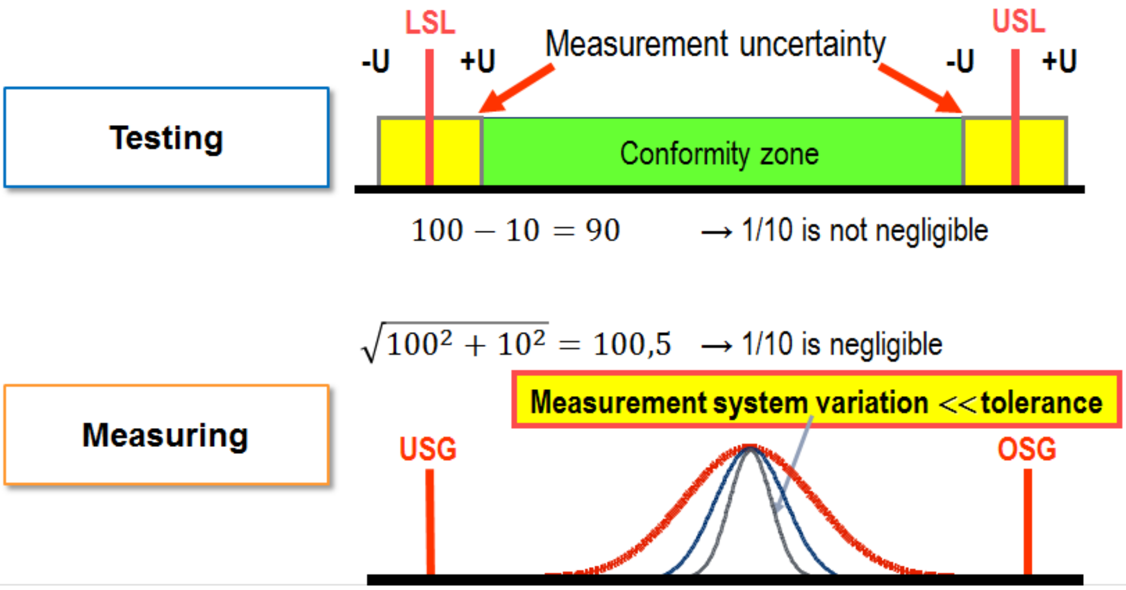

Figure 5: How measurement uncertainty affects a test and a measurement process

Moreover, it is more difficult to conduct capability analyses for processes measuring only a single part (R&D, custom-made products, prototype manufacturing, tool construction, ...) since the number of measurements required for a capability analysis often exceeds the available number of part measurements considerably, the variety of parts is too large and the number of produced parts is generally not sufficient for performing a type-2 study.

Approach according to VDA Volume 5

These were some of the reasons why the German Association of the Automotive Industry (VDA) decided to develop a guideline that includes capability analyses but even calculates the measurement uncertainty that needs to be considered in conformity assessments. By analysing typical measurement processes of a similar type, it is even possible to create a knowledge pool allowing for the assessment of uncertainties even when processes measuring only a single part are concerned. Nowadays, the second edition of VDA Volume 5 applies.

However, the VDA guide has to comply with GUM, i.e. the calculation and expression of measurement uncertainty have to reflect GUM specifications. For a practice-oriented optimisation of the complex GUM methods, VDA defined various conditions and established a simplified approach acceptable in most areas of industrial metrology which is even common practice in other analyses. Other influence components affecting the measurement process are assessed based on standard uncertainties u and illustrated in an uncertainty budget. The user is responsible for the completeness of this budget.

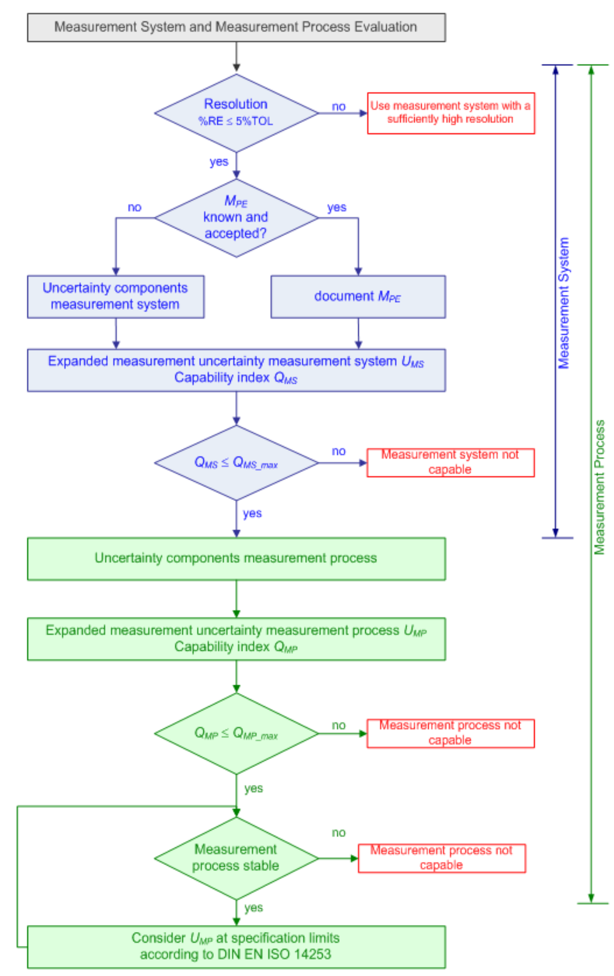

Figure 6: Approach according to VDA Volume 5

VDA Volume 5 provides typical influence quantities that need to be examined but puts the user in charge of ensuring that no other relevant influence quantities are involved. However, even in this case, the one-tenth rule applies, i.e. uncertainty components less than 1/10 of the main component can be neglected. The guide now calculates combined standard uncertainties u_c and expanded measurement uncertainties U from the standard uncertainties starting with the measurement system U_{MS} and continuing with the measurement process U_{MP}. By comparing these expanded measurement uncertainties to the characteristic tolerances, you obtain capability ratios Q_{MS} and Q_{MP} assessing the suitability for a specific application. The difference compared to the AIAG MSA manual, however, is that VDA Volume 5 is based on the international standardised terminology according to ISO 3534 and ISO/IEC Guide 99 (VIM). You may now use the result Q_{MS} for the measurement system to check in advance whether the measurement system is suitable at all for this specific application. The limit according to VDA Volume 5 is $Q_{MS} \leq 15\%$. Only now, you start the logistically more complex evaluation of the entire measurement process Q_{MP}; the recommended limit is $Q_{MP} \leq 30\%$. The calculated expanded measurement uncertainty U_{MP} of the measurement process needs to be considered with respect to characteristic tolerances in conformity assessments according to ISO 14253.

VDA Volume 5 allows the calculation of standard uncertainties u based on any GUM-compliant method but indicates that even the methods of measurement system analysis established in the industry can be applied. Moreover, on the one hand VDA Volume 5 makes it possible to replace the calculation of Q_{MS} by the evaluation of known MPEs and on the other hand it extends the MSA standards by adding the well-known Six Sigma techniques of regression analysis and design of experiments. Only few well-directed trials are sufficient to define most of the relevant uncertainty components.

Comparing the approaches of AIAG MSA and VDA Volume 5

It is hard to make a direct comparison since the methods and targets of both approaches are so different. However, here are some crucial aspects.

- **Limits**

  The limit $Q_{MS} \leq 15\%$ of VDA 5 is similar to the limit $C_g \geq 1{,}33$ that also requires a repeatability of EV≤15% according to many corporate guidelines. However, Q_{MS} includes the bias, at least according to what GUM assesses to be correct. C_{gk} does not support this approach. Moreover, not even the 4th edition of the AIAG MSA manual calculates C_g and C_{gk} in der AIAG MSA. These two capability indices are results of corporate guidelines that even contain different calculation formulas. AIAG's MSA does not calculate any limit but makes decisions based on a significance

test (whose approach is unfortunately wrong).
The same applies to Q_{MP} and %GRR. Even though many corporate guidelines set both limits to 30%, Q_{MP} contains all relevant influences of the measurement system and measurement process while %GRR is only calculated from repeatability, reproducibility and interaction. This is the reason why lowering the %GRR limit to 10% makes sense in the AIAG MSA reference manual. However, since the limits of AIAG MSA refer to the current variation of the manufacturing process whereas VDA Volume 5 and MSA corporate guidelines apply the characteristic tolerance, both decisions are only conditionally comparable.

- **Methods and procedures**

  It is verified that some of the methods and procedures given in the AIAG MSA reference manual are not suitable and/or often lead to wrong conclusions. This is particularly the case for the test for "significant bias" and linearity as well as the ndc statistic within the scope of a GRR study. Users shall always prefer corporate guidelines, especially Bosch booklet 10 "Capability of Measurement and Test Process" which is widely known in German-speaking countries.
  VDA Volume 5 accepts any methods complying with GUM but does not specify a particular one. The guide recommends you to use and extend the MSA procedures applied in practice since they capture all the main influence quantities in only few experiments.

- **Field of application**

  The AIAG MSA reference manual focuses on measurement system capability analyses in a SPC environment. In chapter I section E "Measurement System Variation", it clearly tells apart from measurement uncertainty studies. According to AIAG's MSA, capability describes "... the expected error for defined conditions, scope and range of the measurement system", whereas it defines measurement uncertainty as "... an expression of the expected range of error or values associated with a measurement result". Beyond this definition, the AIAG MSA manual does not offer any methods to calculate an uncertainty from observed components of variation.
  VDA Volume 5 tries to connect the areas of capability and uncertainty based on the definition of capability given in VDA Volume 6.1. It defines capability as the ratio between measurement uncertainty and the tolerance of characteristics. The expression of measurement uncertainty according to VDA Volume 5 is the link between the two definitions mentioned above. It characterizes the variation of values that can be assigned to a measured quantity under defined conditions and in a specified field of application. Due to this aspect, the results of VDA Volume 5 can be applied in capability analyses, releases of measurement processes (e.g. according to ISO/TS 16949) and conformity assessments (e.g. based on ISO 14253-1).

- **Where are these guides applied?**

  Since the AIAG MSA manual looks back on a long history and was able to meet the demands of the former QS9000 standard, it is applied worldwide. Due to its awareness level, it is often associated with GRR studies and referred to in documents applied in the non-automotive industry. However, as mentioned before, you normally do not use the methods as given in the MSA in practice but follow methods that are a kind of quasi-standard in many corporate guidelines.
  The approach of VDA Volume 5 is mainly adopted in companies close to the German association of the automotive industry or by their suppliers who have to meet these requirements, too. Corporate guidelines of the Volkswagen Group (VW, AUDI, Seat, Skoda), Mercedes Benz Cars, BMW and others already include the requirements of VDA Volume 5. Moreover, VDA Volume 5 complies with ISO 22514-7 "Capability of measurement processes" published

in 2012. From an ISO perspective, this is the only general and non-sector-specific standard about capability analyses of measurement and test processes. This is the reason why international companies even outside the automotive industry are likely to apply the methods of ISO 22514-7 and thus of VDA Volume 5 in the future.

ISO/IEC Guide 98 (GUM) ISO 14253	VDA Volume 5 (2nd ed.) ISO 22514	Corporate guidelines about MSA („what people actually do …“)	AIAG MSA 4th ed.
/IEC Guide 98 (GUM) Combined standard measurement uncertainty Degrees of freedom Expandes measurement uncertainty *"It may therefore be necessary to develop particular standards based on this Guide that deal with [...] the various uses [...]."* *"Although this Guide provides a framework for assessing uncertainty, it cannot substitute for critical thinking, intellectual honesty and professional*	Capability of measurement systems	Type-1 study - Cg/Cgk	Bias study (sample or QCC)
	Consideration of type-1 study, linearity and other previous knowledge	Linearity in most cases only maximum bias)	Linearity study (significant slope and intercept)
	- Capability of measurement processes	Type-2 study - %GRR	Gage R&R
	Consideration of type 2/3 study, temperature, test part, multipoint measurements, stability and other previous knowledge	Type-3 study - %GRR	and/or ndc
		Stability	Stability
		(No influences from environment, test part, ...)	(No influences from environment, test part, ...)
ISO 14253: Decision rules for proving conformance or non-conformance with specifications	Decision rules for proving conformance or non-conformance with specifications	No measurement uncertainty - no decision rules	No measurement uncertainty - no decision rules

Figure 7 Comparison of single methods and procedures

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