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Measurement Systems Analysis Requirements for the Aero Engine Supply Chain		

RATIONALE

This technical report is being stabilized and will no longer be updated. This technical report will eventually be cancelled and superseded by AS13100 at a future date to be determined.

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1. SCOPE

This standard defines the minimum requirements for conducting Measurement Systems Analysis (MSA) for variable and attribute assessment on characteristics as defined on the drawing or specification. It does not define the detailed analytical methods for each type of study as these can be found in existing published texts (see Section 2 for guidance).

1.1 Purpose

The aerospace industry is highly reliant on inspection to ensure that parts and assemblies meet drawing requirements. Ensuring that measurement systems are capable and repeatable is vital to the effectiveness of the inspection process.

The purpose of this document is to define the application of appropriate measurement system analysis tools and the acceptance criteria to be applied by the Aero Engine Manufacturers Supply Chain. It shall also provide guidance on the efficiency of application (read across) and mitigation strategies for non-capable measurement systems.

This standard defines the MINIMUM acceptance limits for measurement systems analysis. The purchaser may require different acceptance standards for specific applications.

There may be situations where alternative measurement systems analysis needs to be deployed. These should be agreed between the supplier and the specific purchaser prior to approval.

Case studies are included to provide practical examples of the application of these methods and further reading is also provided in Section 2.

2. REFERENCES

2.1 Applicable Documents

The latest issue of SAE publications shall apply. Nothing in this document shall supersede applicable laws and regulations unless a specific exemption has been obtained. The documents listed below are intended to support the requirements of this document and provide guidance on conducting MSA studies.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

2.1.2 Automotive Industry Action Group (2010). Measurement System Analysis, 4th ed., Detroit, MI.

2.1.3 ASTM E2782, Standard Guide for Measurement Systems Analysis.

2.1.4 Wheeler, D. J. and Lyday, R. W., Evaluating the Measurement Process, SPC Press, Inc., Knoxville, TN, 2006.

2.1.5 "Evaluating the Measurement Process III - Using Imperfect Data" by Donald Wheeler.

2.1.6 Minitab support documentation – www.minitab.com

2.2 Definitions

ACCURACY: How close the measured value is to the 'accepted reference value'.

ACCURACY ERROR OR BIAS: The difference between the observed average value of measurements and a known true value or accepted reference value. Accuracy Error is measurement error not captured in most MSA evaluations and must be considered in the overall assessment of the measurement system. Bias is discussed further in 8.2.7 of this standard.

NOTE: Observed Accuracy Error may be additive to MSA error and the combined values shall not violate Table 2 requirements. An example of Accuracy Error would be when inspecting a feature with a known value of 0.006 the average observed value is 0.0075. This is an accuracy error of 0.0015.

This is not typically seen in off the shelf inspection devices but very common in purpose built inspection devices.

ACCURACY RATIO: The ratio between the total part tolerance and the total calibration tolerance of the measurement equipment.

ARTEFACT: An object of known size, shape, chemical composition, etc., that is used to test the measurement system condition by comparison of the known artefact characteristic against the measured result. Artefacts can be a component which is measured in a number of ways to establish an acknowledged known measurement value. Artefacts can also be calibration masters or an item which has been calibrated to accurately determine its characteristics.

ATTRIBUTE: A qualitative measure of a property that is of interest. This may be binary (pass/fail, good/bad, etc.) or ordinal if the values can be ranked (e.g., low, medium, and high).

CORRELATION: The degree to which two or more factors are statistically related to each other and vary together. This does not necessarily prove a cause and effect relationship just that they appear to show a link.

CRITICAL FEATURES: Those characteristics of an item which, if nonconforming, may result in hazardous or unsafe conditions for personnel using, maintaining or depending on the product; or which may prevent or seriously affect the satisfactory operation or functioning of the product. Specific Purchaser Feature Classifications may exist.

GAUGE REPEATABILITY & REPRODUCIBILITY (GR&R): A study used to determine how much variation is present in a measurement system by combining the equipment variation (repeatability) with the system variation (reproducibility). See 8.2.4 of this standard

LINEARITY: (1) An assessment of accuracy through the defined range of expected measurements in any inspection system. (2) The ability of the measurement system to consistently measure across the intended range with very little or no variability. Lack of Linearity is typically seen in gauges which inspect parts that change geometrically and materially at the same time, with instruments at fixed locations and angles. It is also typical for process related evaluations where process parameters may change throughout the evaluation cycle.

MAJOR FEATURES: Those characteristics of an item, other than critical, which if nonconforming, may result in operational or functional failure of the item, or which materially reduce the usability, physical or functional interchangeability or durability of the product for its intended purpose. Specific feature specifications will be defined by the purchaser.

MEASUREMENT SYSTEMS ANALYSIS (MSA): The process of evaluating the fitness for purpose of a measurement system, including methods such as Gauge R&R, Attribute Agreement, Bias assessment, Stability assessment, Linearity assessment, etc.

MINOR FEATURES: Those characteristics of an item which, if nonconforming, do not materially reduce the usability, physical or functional interchangeability or durability of the product, or are departure from established standards having no significant bearing on the effective use or operation of the product. Specific feature specifications will be defined by the purchaser.

NUMBER OF DISTINCT CATEGORIES: The number of distinct categories within your measurement data that the measurement system can distinguish.

PRECISION: How close the repeated measurement results are to each other.

PURCHASER: The purchaser issuing the purchase order for the part that is subject to the measurement capability acceptance.

REPEATABILITY: The ability of the measurement system to give the same result when measuring the same feature multiple times using the same elements of the system; e.g., gauge, operator, environment, fixture, etc.

REPRODUCIBILITY: The ability of the measurement system to give the same result when elements of the system, such as operator or environment, are changed.

RESOLUTION: The ability of the gauge to detect changes in the characteristic being measured and discriminate between measurement values.

STABILITY: A measure of how variation changes over time. This can be classified as short term or long term stability depending on the time frame involved.

SUPPLIER: A supplier is any manufacturer of systems, sub-systems, assemblies, components and materials for use within the Aero Engine Supply Chain.

VARIABLE: Something that is liable to change and is not a fixed value. There may be one or more causes of the variation either acting independently or together. Variable or continuous data may take on any value within a finite or infinite interval depending on the resolution of the measurement system used to capture that value.

3. APPLICABILITY

This standard is intended for businesses that design and/or manufacture products throughout the Aero Engine Supply Chain. The minimum requirements for both variable and attribute measurement systems are defined where used to validate product in its final condition.

It is expected that these requirements shall be flowed down to all sub tiers within the supply chain and included within their Quality Management System.

Any additions or exclusions to this standard must be agreed with the purchaser.

The scope of application of these requirements shall be defined by the purchaser, and this may include part numbers, processes, etc.

4. OVERVIEW OF MEASUREMENT SYSTEMS ANALYSIS (MSA)

A Measurement System is the combination of people, equipment, materials, methods, environment, analysis and decisions made on the measured results. All measurement systems have a level of uncertainty associated with them because of variation in these factors. MSA is the method of identifying the level of uncertainty of the whole system so that we can determine if the Measurement system is 'fit for its intended purpose,' i.e., the level of measurement variation is not significant (Table 2 shows the acceptance limits for MSA).

There are several types of MSA; which type is required will depend on the type of data being measured and the influences on the system (see Figure 2).

The purpose of MSA is to identify the total variation present in the system so that actions can be taken to effectively control it and ensure repeatable and accurate measurements. These studies should be conducted to represent the 'real world' as much as possible; e.g., range of inspectors, parts that cover the whole specification, normal working environment, etc.

MSA shall be conducted as part of New Product Introduction to validate the measurement system prior to production. There are also situations where MSA should be repeated, these include: changes to gauge design, refurbishment/repair, environment, product design change to the feature being measured, etc.

Table 1 describes situations where MSA is required. Note that in this context MSA refers to the methods described in Table 2. Which tests are applicable will depend on the type of data being measured and the influences on the system (see Figure 2).

This standard defines the minimum acceptance limits for MSA and provides guidance for most situations but there may be situations where alternative methods are required. In such cases they must be approved by the purchaser.

Table 1 - MSA applications

Event	Event Description	Action
1	New inspection device or method introduction.	Perform MSA
2	New/Changed Production Process.	Evaluate current or Perform MSA
3	Any significant change to the current inspection device or method: i.e., equipment, operator, environment, location, sequence, calibration standard, Inspection house, CMM software or hardware change	Evaluate current or Perform MSA
4	Following a product escape related to (or suspected to be) from the Measurement System (nonconforming material left the facility).	Evaluate current or Perform MSA
5	Change in how an inspection device or method is used, or its application*. For example: 1. When changing from simple geometry to complex. Moving from simple linear dimensions with flat parallel surfaces to non-flat (non-parallel) surfaces with geometric constructions required. 2. When changing from similar to non-similar product characteristics. Moving from visual inspection of edge breaks with dimensional requirements to visual inspection of cosmetic appearance requirements.	Perform MSA
6	Product requirements are changed to be more restrictive or tightened.	Recalculate from base data or Perform MSA
7	As part of a First Article Inspection (FAI) following a lapse in use of more than 24 months.	Evaluate current MSA
8	Existing inspection device or method is being used to accept product and has not previously been evaluated per this standard as directed by purchaser.	Perform MSA where required
9	Product audit non-conformance or product investigation when suspected to be from the measurement system.	Evaluate current or Perform MSA
10	To verify a measurement system is adequate before SPC.	Perform MSA where required

* Different product with similar geometry and tolerances are typically not considered a change in application.

NOTES:

- Specifications within this table apply unless otherwise stated by the purchaser
- The term “evaluate” means a confirmation that the MSA study characteristics are still valid and additional measurement uncertainty has not been induced

5. ORGANIZATION AND COMPETENCE REQUIREMENTS

The correct training of MSA practitioners is key to the successful outcome of the process. Each supplier shall employ or have access to a practitioner who has appropriate experience and can demonstrate competence that includes all elements of this standard. It is expected that the practitioner will periodically confirm compliance to the standard. Individuals involved in the study must be suitably trained and competent in the measurement task. They must be representative of the measurement system users (see 8.1.3). The MSA study must be lead or facilitated by a person trained and competent in the methodology covered in this standard.

The supplier shall nominate a suitably qualified and experienced person from within their own organization as accountable for deployment of this standard and respective compliance.

6. QUALITY SYSTEM

- The supplier shall have a documented process within its own quality system which meets the requirements of this standard. The process shall be fully implemented and subject to an audit.
- The documented MSA process shall describe the training and competency requirements for practitioners of this process.
- Records of MSA studies identifying measurement systems as capable shall be maintained within the organization's quality system and subject to the same level of record retention as its FAI Records.

7. MEASUREMENT SYSTEMS ANALYSIS REQUIREMENTS

7.1 Pre-Requisites

The pre-requisites and generic requirements for any type of MSA study are:

- The measurement equipment must be calibrated and traceable to a relevant national or international standard.
- The measurement equipment must be maintained in good condition and checked for evidence of damage or wear, which may impact the measurement capability.
- Production parts must be used for studies, except for circumstances where the use of representative parts or artefacts is authorized (see 8.1.1 and 8.1.2). The parts must represent the full tolerance and it is beneficial to include parts just outside the LSL and USL.
- The parts should be as clean and burr free as would be seen by the production inspection method.
- Individuals involved in the study must be suitably trained and competent in the measurement task. They must be representative of the measurement system users (see 8.1.3).
- The measurement system analysis study must be lead or facilitated by a person trained and competent in the methodology covered in this standard.
- An environment representative of the production operation must be used for the MSA study.
- The method used for any study must replicate the conditions in the production process. Where alignment, fixturing, and clamping could influence the measured value, the component must be removed and reloaded between each measurement. Deviation from this requires purchaser authorization.
- During the study, the personnel performing the measurements must not have visibility of either their own or other study participant's previous results.

7.2 Considerations when Planning a MSA Study

MSA Studies require careful planning to ensure that the results are truly representative of the measurement system. The system shall be fully evaluated to identify what could affect the results so that anything likely to contribute to the variation is included in the study. An MSA is essentially an experiment to determine the degree and causes of variation within a measurement system. As such, careful use of Design of Experiments is recommended. See also 8.1.

Factors that need to be evaluated include:

- Environment – temperature, humidity, contamination, vibration, electromagnetic radiation, etc.
- Location – different buildings, sites, etc.
- Part variation that will affect the measured value (surface finish, flexibility, shape, size, etc.)
- People – shift patterns, times of the day, experience levels
- Process – fixtures, probes, accessories, etc.

A useful way of visually expressing the factors is to use a tree diagram example shown below.

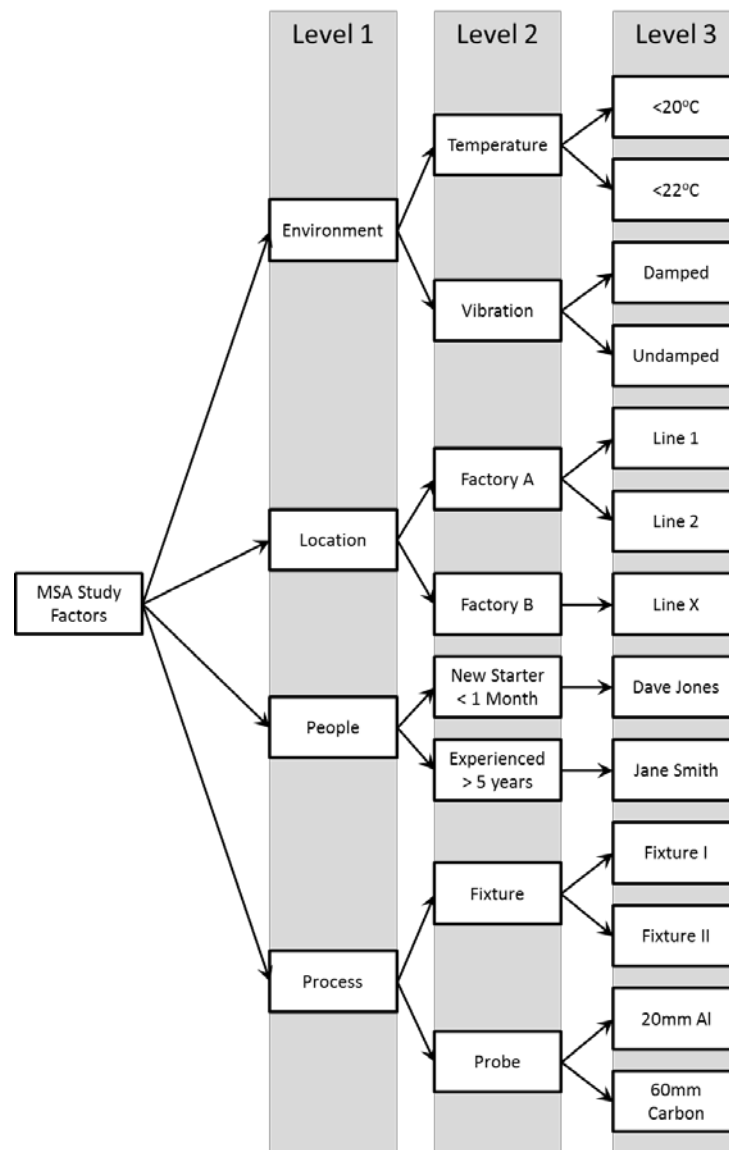


Figure 1 - Planning an MSA study

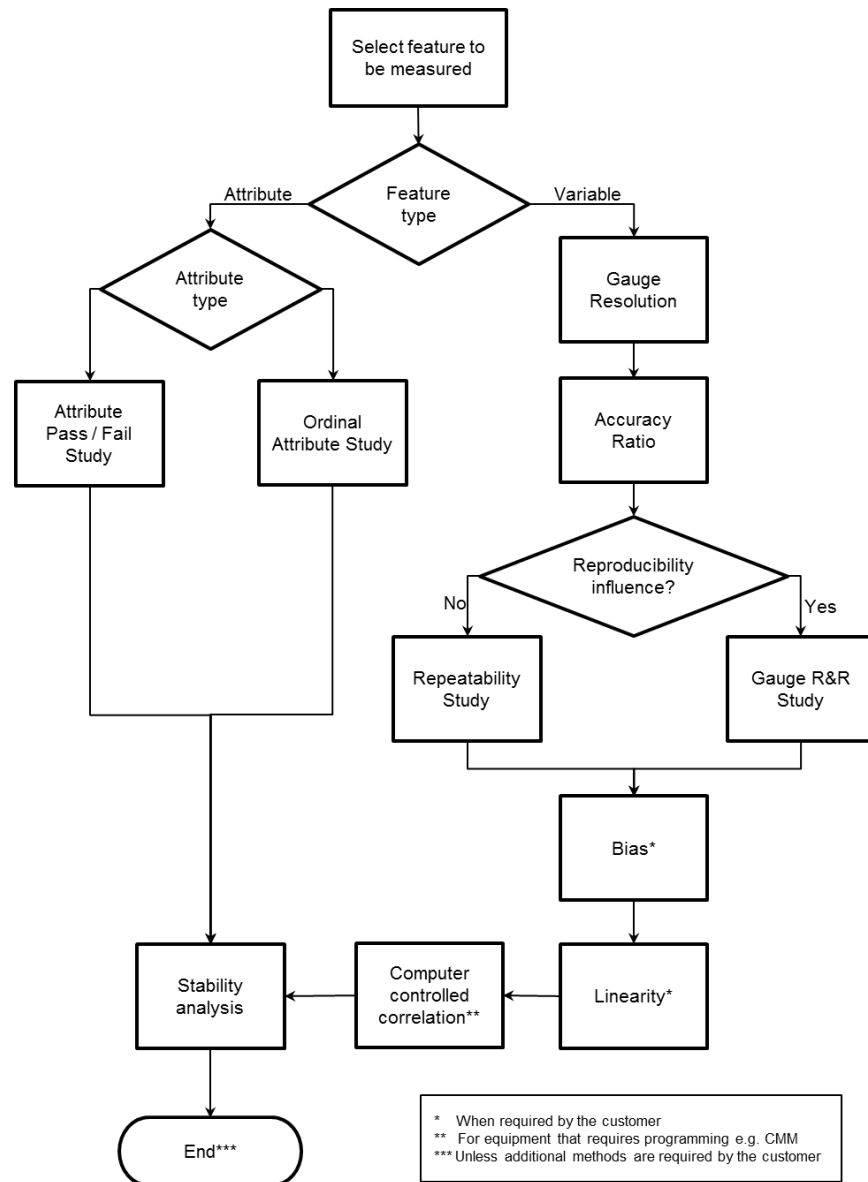


Figure 2 - Selecting the appropriate measurement systems analysis methods

Figure 2 shows methods of assessing MSA that can be applied in a logical order. The selection of methods should be based on purchaser requirements (i.e., not all tests may be required). The type of measurement being conducted and the study characteristics such as part availability, number of operators, number of repeat measurements, etc., many influence the selection of one method over another. The detailed descriptions and case studies within this standard can guide the user to the selection of MSA methods. See 7.2 of this standard.

7.3 MSA Minimum Requirements

Table 2 - Minimum requirements for MSA

Method	Feature Category			Comments
	Critical	Major	Minor	
Resolution	$\leq 10\%$ of total tolerance ***			Based on total tolerance.
Accuracy ratio**	Requirement = 10:1		Requirement = 4:1	Values up to 4:1 may be acceptable when approved by the purchaser
Accuracy Error / Bias	$\leq 10\%$ of total tolerance			Purchaser requirements may override this
Repeatability	$\leq 10\%$ of total tolerance	$\leq 20\%$ of total tolerance	$\leq 30\%$ of total tolerance*	Purchaser requirements may override this
Gauge R&R	$\leq 10\%$ of total tolerance	$\leq 20\%$ of total tolerance	$\leq 30\%$ of total tolerance*	Purchaser requirements may override this
Computer driven measurement systems correlation	$\leq 10\%$ of total Tolerance		$\leq 20\%$ of total Tolerance	Purchaser requirements may override this
Linearity**	$\leq 1\%$ of total tolerance		-	
Attribute Study: pass/fail	Kappa ≥ 0.8		-	Only required on operator dependent interpretation
Attribute study: ordinal	ICC ≥ 0.75		-	Only required on operator dependent interpretation

* Repeatability and Gauge R&R studies are only required for minor features when there has been an escape related to that feature or when required by the purchaser (see Table 1).

** Only required when specified by the purchaser or where the feature is a datum.

*** May permit lower resolutions provided an acceptable GR&R is obtained.

NOTE: All statistical calculations assume ± 3 standard deviations unless otherwise specified by the purchaser.

In cases where high process capability are available, best practice is to check measurement capability against the “% of process variation” rather than the “% of total tolerance” seen in Table 2. As process variation is less than the tolerance, applying these limits will ensure the measurement system adequately controls the process and the manufacturing process is not limited by the measurement system.

8. ELEMENTS TO CONSIDER WHEN CONDUCTING MSA

8.1 MSA Design Factors

The following section are designed to provide guidance when conducting MSA studies. Where this guidance cannot be followed as written then alternatives may be appropriate and in such cases this should be agreed with the purchaser.

MSA studies should be designed to find all of the existing variation in the measurement process so that action can be taken to mitigate it and provide a capable and repeatable measurement system.

8.1.1 Sample Selection

Factors affecting the selection of samples include:

- Criticality of dimensions – the degree of confidence required for critical dimensions is higher, therefore, more data is required.
- Part configuration – large parts, inaccessible features and low numbers of available samples may dictate low sample sizes which must be recognized in any reports.
- Purchaser requirements – specific requests regarding the selection of samples may be defined by purchasers.

Sample parts shall represent the entire production operating range and ideally the entire allowed tolerance range.

The analysis techniques used assumes that there is statistical independence of the individual data points so must be taken to randomize the measurements ensuring that operators are not able to identify parts.

In some instances it will not be possible to obtain a fully representative sample of product. In these instances, a feature that is representative of the manufacturing process and size can be used. Where a representative part or linearity study is used, to compensate for a poor sample of parts, this must be documented and approved by the purchaser.

8.1.2 Sample Numbers

As with any statistical technique, the larger the sample size, the more accurate the results. The number of samples is, however, very dependent on the measurement process and the type of study being conducted. Studies where the measured characteristic has significant variation will require a high number of samples to statistically describe the process, 10 samples or more are required. Where this cannot be achieved, it should be declared as part of the MSA acceptance report.

Processes where the measurement system is subject to human intervention will require a higher number of repeat measurements per inspector. Each inspector shall measure each sample three (3) times or more. As a minimum and where samples show a good level of control, each person shall measure each sample twice.

Attribute studies require a much larger sample size, typically 30 or more.

Where automated measurement systems are used (CMMs, etc.) the human influence should have negligible effect. The number of repeats can, therefore, be reduced to a minimum of five (5) when proving repeatability of automated measurement systems or where the operator has no influence on the measured results (see case study 10.1 in this standard).

8.1.3 Operators

Where possible, a representative sample of operators who normally use the measurement equipment shall be included in the study. If this is not possible then a minimum of two (2) people shall be selected. Important factors to consider include:

- The most and the least experienced people
- People who work in different locations
- People who work on different shifts
- Any physiological factors that may affect the measurement process; e.g., left and right handed people, different levels of eyesight acuity, height, strength, etc.

All participants in the measurement study shall be trained and experienced in the task. Do not include people who do not normally carry out the measurement activities as part of their day-to-day duties. Do not include 'experts' like Metrologists or Manufacturing Engineers unless they are representative of typical users.

8.1.4 Low Sample Sizes

Ideally at least ten parts or features should be available for the measurement study. Using three operators measuring each part a minimum of two (2) times would give sixty data points, which is sufficient to give meaningful result.

Sometimes though there may not be sufficient parts available. There are a number of ways that this problem can be overcome:

- Conduct the study over a longer period of time as parts become available. This also has the advantage of incorporating any time based factors into the study.
- Use multiple features on one (1) part. For example, a slotted disc may contain several identical features which can be identified and used to conduct the study. Potential problems with using this method include randomizing the measurements effectively and a lack of variation in the features, but with care this can be accomplished. Be aware that this method may exclude sources of variation that could be affecting the measurement values and any results obtained may not be fully representative.
- Use scrap parts. So long as the part is representative of a finished part (all features are present and the geometry and surface finish are correct) then non-conforming parts can be used. Ideally use features on the parts that are conforming in case that non-conformance affects the measurement.
- If no other options are available then smaller sample sizes may be used but a note should be added to the final report highlighting the small sample size and higher risk of the results being unrepresentative. Care should be taken as a low sample can also lead to a reported low number of distinct categories which may or may not be a true problem.

8.1.5 In Part Variation

When conducting a measurement study, it is important to identify variation in the part that could affect the measurement result. As an example consider measuring a shaft diameter where the diameter of the shaft is not perfectly round. Running a measurement study will capture both variation due to the measurement system, and variation of the diameter shape. It is advisable to identify the amount of in part variation before the study is conducted. Marking the component to ensure measurements are taken in the same place will limit the in part variation, but the study will not then be representative of the measurement process seen in production. Where in part variation is considerable, compared to the size of the tolerance, this should be declared to the purchaser as part of the measurement study.