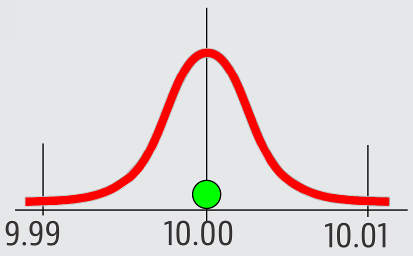
METROLOGY MATTERS

METROLOGY DECISION RISK

Poster 1 in the “Path to GOOD DECISIONS” series

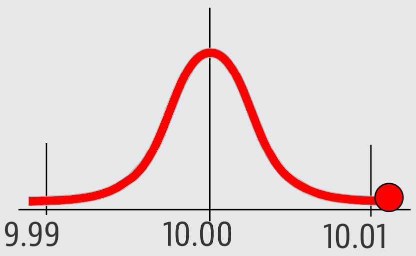
01 Metrology decisions have 4 possible outcomes, each with its own economic consequences:



1. Accept a good part

The system works!

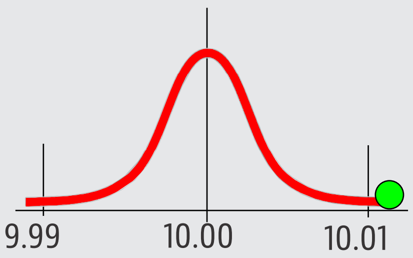
Producing maximum value return to the organization



2. Reject a bad part

The system works!

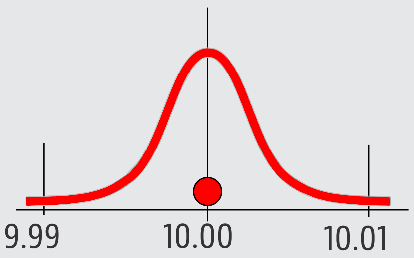
Loss of time & material costs to complete the part to the inspection point. Downstream risks avoided



3. Reject a good part

The system fails!

Loss of time and material costs to complete a good part and then adding it to scrap and rework



4. Accept a bad part

The system fails!

Will the failure be detected during final assembly and test resulting in rework costs and delivery delays?

Will the failure be detected in the field with warranty costs?

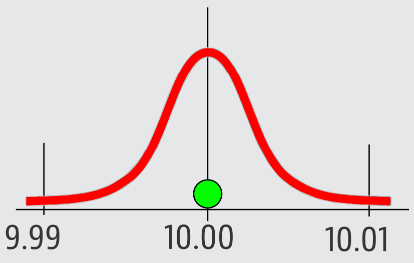
Will the failure result in product liability costs and possible litigation costs?

If it never fails, the design specification fails because a failing part functions properly

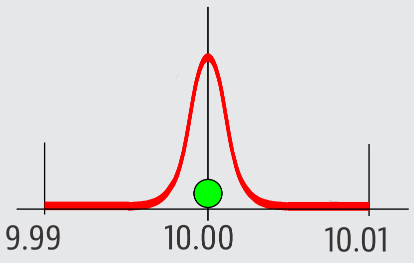
02 A valid and capable measurement system can be confidently relied on to make decisions 1 and 2. A measurement system that allows decisions 3 and 4 exposes the organization to potentially devastating losses

03 A valid and capable measurement system enables us to both:

Make good part acceptance decisions

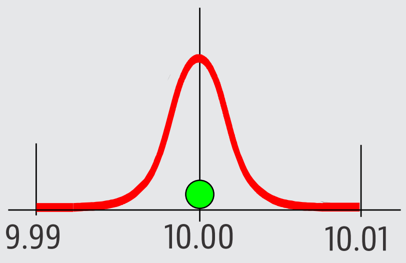


Make good decisions about manufacturing process capabilities and expectations of process yield



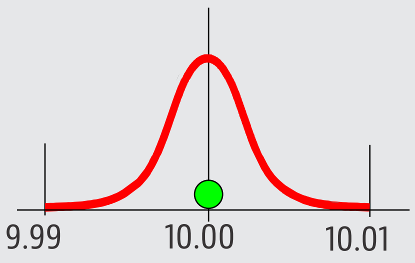
Process Capability = 2

Expected failures less than 1 PPM



Process Capability = 1.33

Expected failures 63 PPM



Process Capability = 1

Expected failures 2700 PPM

Without a valid and capable measurement system, decisions on accept/reject and manufacturing process control cannot be relied on.

04 The path to GOOD DECISIONS:

Identify critical feature nominals & tolerances → Identify the required level of confidence in measured results → Identify the Tolerance to Uncertainty Ratio (TUR) required → Identify the measurement system(s) meeting confidence and TUR for specified features → Evaluate the measurement system to prove its ability to make “GOOD DECISIONS”

Metrology Matters is a project of these organizations to provide basic metrology fundamentals to manufacturing.

www.gagesite.com/metrologymatters

PRODUCTIVITY QUALITY INC
QUALITY STARTS HERE

IIGDT
International Institute of Geometric Dimensioning & Tolerancing

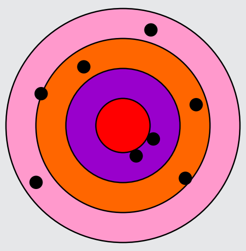
AIS ADVANCED INSPECTION SERVICES

METROLOGY MATTERS

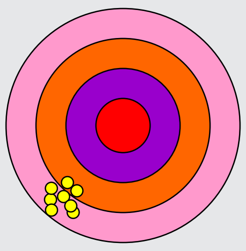
SELECTING A MEASUREMENT SYSTEM

Poster 2 in the “Path to GOOD DECISIONS” series

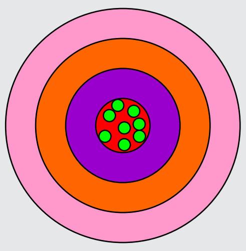
01 Accuracy and Repeatability



Neither accurate or repeatable



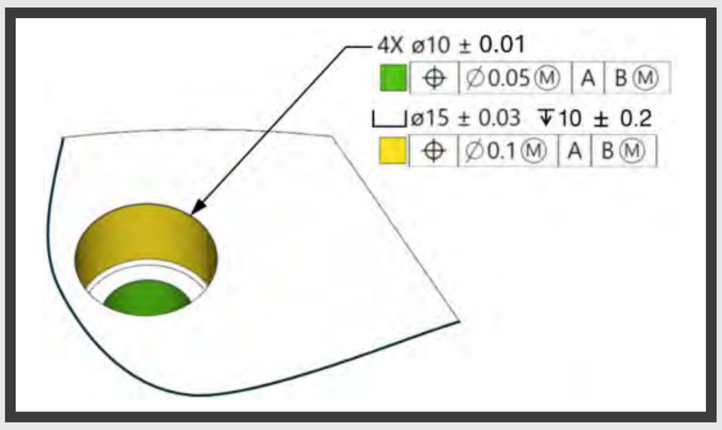
Not accurate but repeatable



Accurate and repeatable

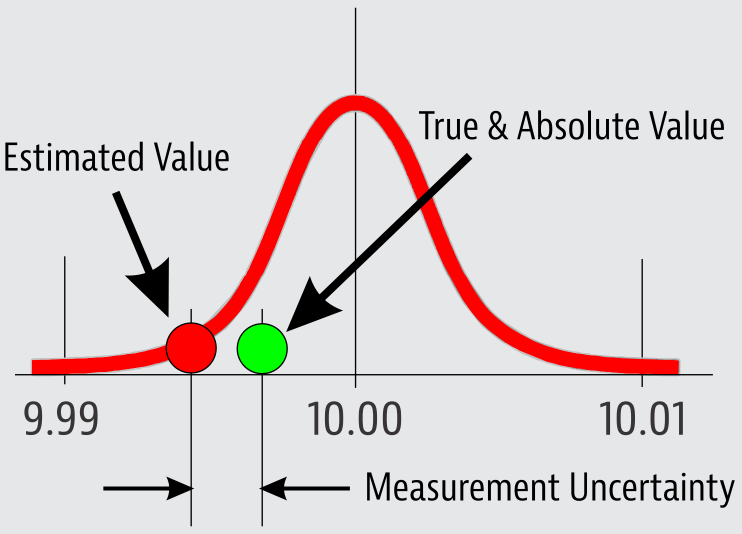
A result is called **valid** if it is both accurate and repeatable.

02 Is accurate and repeatable enough to make confident decisions?

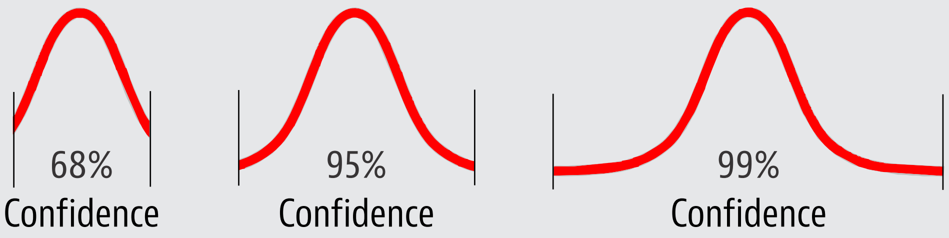


Our decision:
A 10 mm bore with a +/- 0.010 mm tolerance

03 Every measured value is an estimate of the true and absolute value. The “goodness” of this estimate determines the uncertainty of measurement and how much confidence we can have in our measured value.

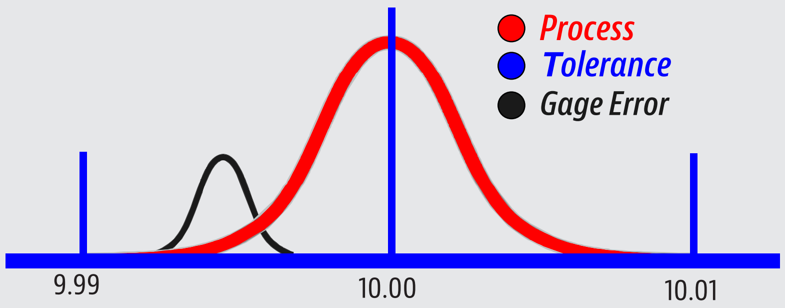


04 We describe the “goodness” of our measured estimate with a confidence interval that defines how much risk we can accept.



“95 times out of 100 the true value falls inside my confidence interval”

We have identified our feature, its nominals, tolerances, and our desired confidence level. Next is identifying the measurement system to be used. To do that we need to define our Tolerance to Uncertainty Ratio (TUR).



4:1 TUR, 25%, is the practical standard used for our example

Our measurement device needs to prove itself capable to:
0.02 * 0.25 = 0.005 mm at U95 (95% Confidence Interval)

Metrology Matters is a project of these organizations to provide basic metrology fundamentals to manufacturing.

www.gagesite.com/metrologymatters

PRODUCTIVITY QUALITY INC
QUALITY STARTS HERE

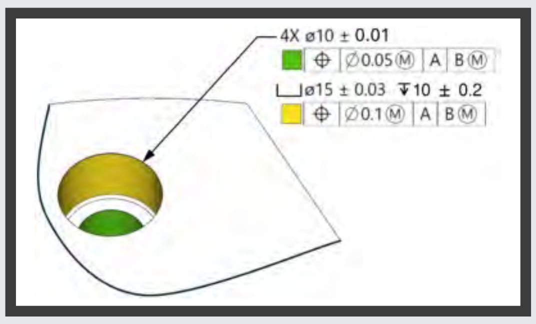
ADVANCED INSPECTION SERVICES

METROLOGY
MATTERS

EVALUATING CMM PERFORMANCE STANDARDS

Poster 3 in the “Path to GOOD DECISIONS” series

01 The problem to solve:



Tolerance = +/- 0.01 = 0.02
0.02 * 0.25 TUR = 0.005 mm
at U95 (95% Confidence Interval)

02 CMM Standards

The ISO 10360 series of measurement standards are the universally accepted guidance for evaluating CMM performance

ISO 10360

ISO 10360-2:2009
Geometrical product specifications (GPS) - CMMs used for measuring 3D linear dimensions

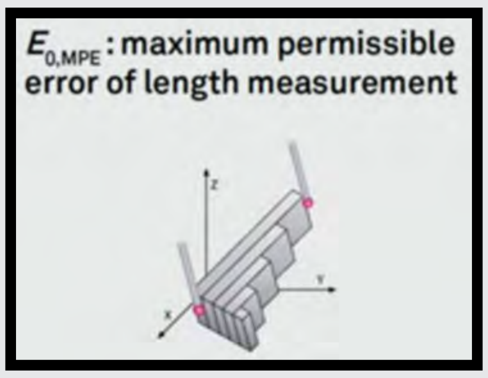
ISO 10360-5:2020
CMMs using single and multiple stylus contacting probing systems using discrete point and/or scanning measuring mode

ISO 10360-7:2011
Part 7: CMMs equipped with imaging probing systems

ISO 10360-10:2021
Laser trackers

ISO 10360-12:2016
Articulating arm coordinate measuring machines (CMM)

03 For our example, we will use ISO 10360-2 where we can find a maximum permissible error of measurement for a contact probe CMM. The calibration artifact is a stack of gage blocks or a step gage



Hexagon 454 CMM Specification:

PERFORMANCE SPECIFICATIONS

According to ISO 10360-2:2009:

$E_{0,MPE}$: 3.1 + L / 1000

Breaking it down:

E0, MPE: 3.1 + L / 1000

E0, MPE
Maximum permissible error with optimal stylus length

Base accuracy 3.1
or 0.0031 mm

Divisor allowing for part length

3.1 + (10 mm length / 1000) = 3.11 = 0.0031 mm

04 Our tolerance has been defined as 10.0 +/- 0.01. The uncertainty portion of our TUR ratio estimate can be defined through:

Manufacturer’s Specification

GR&R Study

Measurement Uncertainty Budget

We’ll start with the manufacturer’s specification for three potential systems

Used CMM, ISO Cal

Base Accuracy	6
Length Divisor	500
Total Tolerance	0.02
Feature Size	10
Calculated Error	0.0060
% of Tol. (~TUR)	30.10%

Hexagon SF 454 MFG Spec.

Base Accuracy	3.1
Length Divisor	1000
Total Tolerance	0.02
Feature Size	10
Calculated Error	0.0031
% of Tol. (~TUR)	15.55%

Hexagon Global MFG Spec.

Base Accuracy	1.3
Length Divisor	333
Total Tolerance	0.02
Feature Size	10
Calculated Error	0.0013
% of Tol. (~TUR)	6.65%

Metrology Matters is a project of these organizations to provide basic metrology fundamentals to manufacturing.

www.gagesite.com/metrologymatters

PRODUCTIVITY QUALITY INC
QUALITY STARTS HERE

IIGDT

AIS
ADVANCED INSPECTION SERVICES

METROLOGY MATTERS

MAKING MEASUREMENT UNCERTAINTY BUDGETS

Poster 4 in the “Path to GOOD DECISIONS” series

01

The Hexagon SF 454 has a TUR of 6.5:1 or 15.5%, which exceeds our goal of better than 4:1 or 25%. Consideration must also be given to the TUR value in comparison to other tests such as Gage Repeatability & Reproducibility (GR&R) and an Uncertainty Budget (UNC)

Base Accuracy	3.1
Length Divisor	1000
Total Tolerance	0.02
Feature Size	10
Calculated Error	0.0031
% of Tol. (~TUR)	15.55%

Hexagon SF 454 MFG Spec.

02

	TUR	GR&R	Uncertainty Budget
Advantages	Can be determined before any part measurement takes place. Straightforward calculation.	Includes the effect of the interaction of the gage, parts, and operators.	Includes the effect of the interaction of the gage, parts, operators, and other influences like surface finish, form, and environment calculations.
Disadvantages	Ignores many influences that will effect gage capability.	Time consuming and demands for following proper procedure. Looks at repeatability and assumes accuracy.	Time consuming. Requires careful analysis and quantification of hundreds of potential measurement influences.
Measurement Artifact	Traceable artifact identified in the applicable standard and applied in system calibration.	Multiple production parts and assumes use of traceable artifact in system calibration.	Traceable calibration standard, production parts, other traceable artifacts as analysis identifies.

03 Comparison

Tolerance to Uncertainty Ratio

Base Accuracy	3.1
Length Divisor	1000
Total Tolerance	0.02
Feature Size	10
Calculated Error	0.0031
% of Tol. (~TUR)	15.55%

GR&R

Pooled Standard Deviation	0.00090
Sigma Multiplier	4
R&R Value	0.00359
Total Tolerance	0.0200
% of Tol. (~TUR)	18.0%

Uncertainty Budget

GR&R Data	13.56%
Resolution	2.13%
CTE	1.58%
UNDE	0.16%
Accuracy Statement	66.02%
Surface Roughness Rz	15.06%
Form Deviations	1.51%
Combined Standard Uncertainty	0.00187
Expanded Uncertainty (K=2)	0.00375
% of Tol. (TUR)	37.48%

04 Now what?

TUR = 15.5% GR&R = 18% UNC Budget = 37.5%

These are ***expected results***. GR&R and UNC calculation bring in additional sources of measurement uncertainty. Following the Metrology Risk poster will help determine the right path for your application. If the risk consequences are great, like a critical medical device or flight safety aerospace component, the time and effort of developing an uncertainty budget is easily justified.

Want to learn more? Join us for our 3-day Metrology Boot Camp course on metrology basics and measurement uncertainty.

Metrology Matters is a project of these organizations to provide basic metrology fundamentals to manufacturing.

www.gagesite.com/metrologymatters

PRODUCTIVITY QUALITY INC
QUALITY STARTS HERE

AIS ADVANCED INSPECTION SERVICES