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Measurement Decision Risk - The Importance of Definitions

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Introduction

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The idea behind this presentation is how the difference in definitions can change the application.

1. Look at history, concepts, and definitions.
2. Link the TUR to measurement decision risk.
3. Apply the Z540.3 TUR and measurement decision risk.



Development of Measurement Decision Risk

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- Roots are based on consumer and producer risk analysis first developed in the late 1940's and early 1950's
 - Alan Eagle
 - Frank Grubbs, and Helen Coon.
- Eagle's 1954 paper provided
 - methods for calculating the consumer and producer risk
 - methods for establishing “test limits,” referred to as guardbands today.
- The focus of the paper was to analyze and mitigate the “test errors”
- The key point to Eagle’s method was quantifying and using measurement decision risk as a part of the manufacturing process.
- This concept is applicable to any processes where decisions are based on measurements.



Development of MDR and the TUR

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- In 1955, U.S. Navy needed improved measurement reliability in the guided missile program.
- In response, Jerry Hayes authored TM No. 63-106. Aspects of this TM are still relevant today
 - Calibrated equipment needed for testing,
 - Establishment of reasonable testing risk levels,
 - Reasonable design tolerances,
 - Adequate procedures for testing.
- Building on Eagle's work, Hayes proposed using a "family of curves" to determine specific testing risk.
 - The down-side was a new family of curves had to be established for each change in process or design tolerance.
 - Computing consumer risk was very arduous with slide rules
 - A 4:1 accuracy ratio was established for Navy policy



Existing Definitions

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American Society for Quality (ASQ)

Test accuracy ratio - (1) In a calibration procedure, the test accuracy ratio (TAR) is the ratio of the accuracy tolerance of the unit under calibration to the accuracy tolerance of the calibration standard used.

$$\text{TAR} = \frac{\text{UUT_Tolerance}}{\text{Std_Tolerance}}$$

Test uncertainty ratio - In a calibration procedure, the test uncertainty ratio (TUR) is the ratio of the accuracy tolerance of the unit under calibration to the uncertainty of the calibration standard used.

$$\text{TUR} = \frac{\text{UUT_Tolerance}}{\text{Std_Uncertainty}}$$



Existing Definitions

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NASA's Space Shuttle Program, NSTS 5300.4 (1D-2)

Paragraph 4: Article or Material Measurement Processes

The Expanded Uncertainty in any article or material measurement process shall not exceed ten percent of the tolerance of the article or material characteristic being measured.

Paragraph 5: Calibration Measurement Processes

... the Expanded Uncertainty in any calibration measurement process shall not exceed 25 percent of the tolerance of the parameter being measured.



Existing Definitions

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ANSI/NSCL Z540.1-1995

Interpretive Guidance for Section 10.2 of the Handbook

As a default alternative to doing an uncertainty analysis, a laboratory may rely on a Test Accuracy Ratio (TAR) of 4:1. A TAR of 4:1 means that the tolerance of the parameter (specification) being tested is equal to or greater than four times the combination of the uncertainties of all the measurement standards employed in the test.

If it is determined that the TAR is less than 4:1, then one of the following methods may be used: uncertainty analysis as described above, guard-banding, widening the specification, or another appropriate method.

Note: Some refer to TARs as Test Uncertainty Ratios or TURs



Existing Definitions

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ANSI/NSCL Z540.3-2006

3.11 Test uncertainty ratio

The ratio of the span of the tolerance of a measurement quantity subject to calibration, to twice the 95% expanded uncertainty of the measurement process used for calibration.

NOTE: This applies to two-sided tolerances.

$$\text{TUR} = \frac{\text{Upper} - \text{Lower}}{2 \cdot U} \quad U = k \cdot u \quad k = 2$$



MDR – The Influence Variables

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Consumer Risk (False Accept Risk) equation based on Eagle's work.

$$CR = \frac{1}{\pi} \int_{(k)}^{\infty} \frac{e^{-\frac{(t^2 + s^2)}{2}}}{(r \cdot (k - t) - b) \cdot (-r \cdot (k - t) + b)} ds dt$$

There are three distinct variables, r , k , and b which influence the results.

$$CR = CR(r, k, b)$$

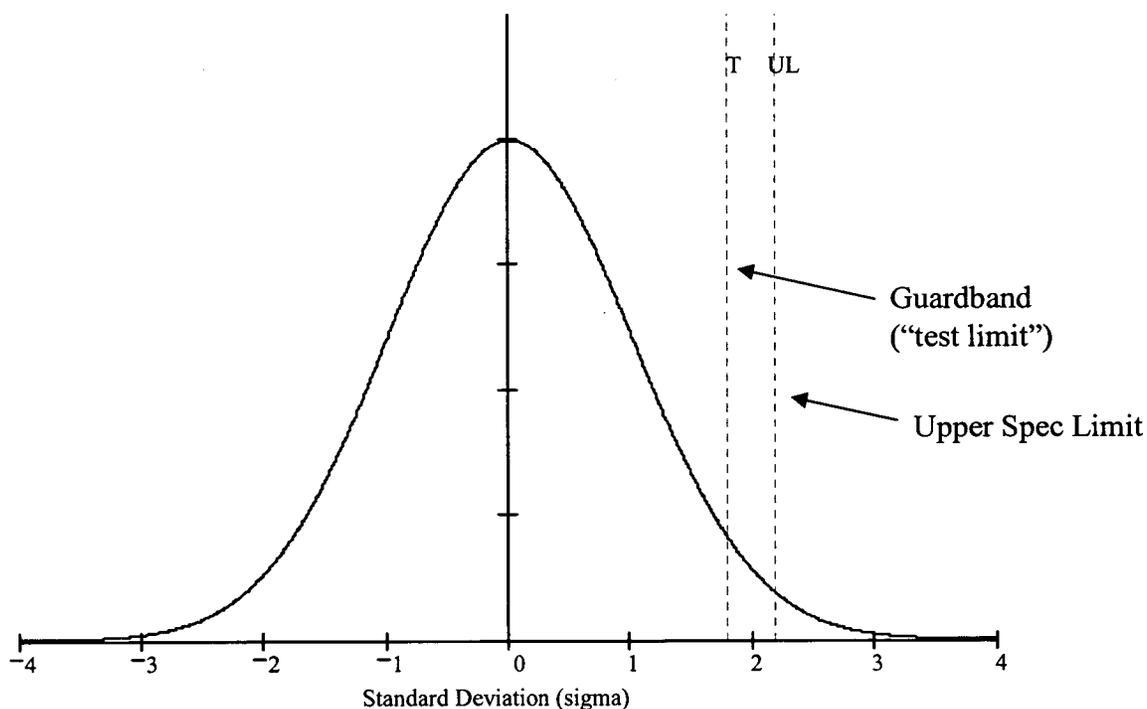


MDR – The Influence Variables

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The variable b is the deviation of the test limits from the spec limits [i.e., $\mu \pm (k\sigma_x - b\sigma_e)$].

For this discussion, the specification limits will equal the test limits (i.e., $b = 0$).

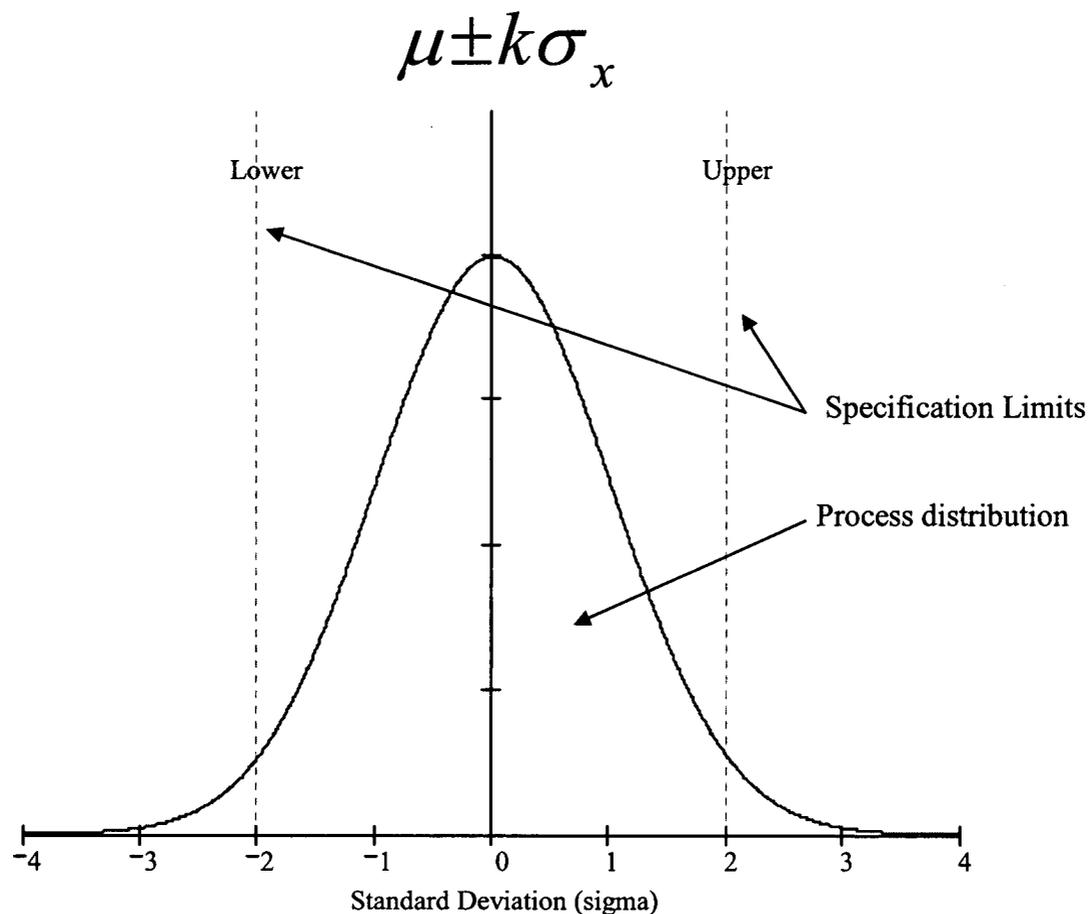




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Variable k is the number of standard deviations the performance specification limit is to the process distribution mean, which is assumed to be centered.





MDR – The Influence Variables

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Variable r is a ratio of two standard deviations. $r = \frac{\sigma_X}{\sigma_e}$

- The numerator σ_X is “the true standard deviation of the product distribution.” In other words, the subject of interest.
- The denominator σ_e is “the standard deviation of the errors of measurement.” Today we call this the measurement process uncertainty.

The variable r is referred to as an “accuracy ratio.”

- It is considered the origin of the TUR, but it is very different.
- It has no confidence limits or coverage factors ($\pm k$). Therefore, r is a pure “uncertainty ratio.”

$$r = \frac{\sigma_X}{\sigma_e} = \frac{u_X}{u_e}$$

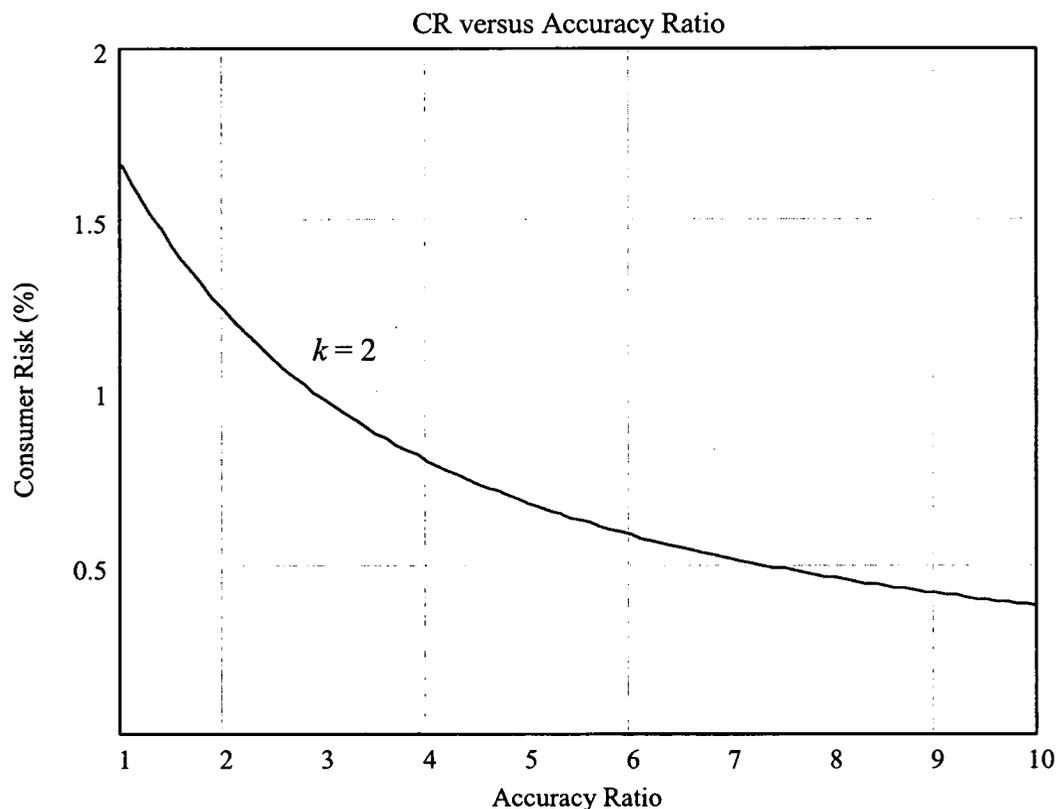


Linking the TUR to Measurement Decision Risk

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The relationship between r and k is shown graphically.

The “knee” of the curve intersects the 1% risk at an approximate r -value of 3:1. Hayes and his colleagues added a little extra margin and thus 4:1 became the “rule of thumb.”





Linking the TUR to Measurement Decision Risk

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The Z540.3 definition helps realign the TUR back to its origins in measurement decision risk.

- To link the consumer risk accuracy ratio to the TUR, the denominator becomes an estimate of the measurement process uncertainty.

$$r = \frac{\sigma_x}{\sigma_e} = \frac{\sigma_x}{u_e}$$

- Using the relationship of the tolerance to the product mean $\mu \pm k\sigma_x$, the TUR can be represented as a ratio of intervals ($\pm k\sigma$).

$$\text{TUR} = \frac{\text{Upper} - \text{Lower}}{2 \cdot U_{95}} = \frac{\text{Upper} - \text{Lower}}{2 \cdot k_e \cdot u_e} = \frac{2 \cdot k_x \cdot \sigma_x}{2 \cdot k_e \cdot u_e} = \frac{k_x \cdot \sigma_x}{k_e \cdot u_e}$$



Linking the TUR to Measurement Decision Risk

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- The k in the numerator represents the k factor in the consumer risk equation. This is the key that links the TUR and measurement decision risk.
- The value of k for a calibration process can be represented by the End of Period Reliability (EOPR) for the Unit under Test (UUT).
 - An EOPR of 95.45% would then be $k = 2.0$ for a normal distribution.



Example – Digital micrometer

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Micrometer and standard information.

Parameter	Digital Micrometer 0-1 inch (0-25.4 mm)	Gage Block, Class 2
Tolerance	± 0.0001 inch (± 2.54 μm)	± 0.000004 inches (± 0.1016 μm)
Resolution	± 0.00005 inch (± 1.27 μm)	N/A

$$TAR = \frac{UUT_tolerance}{Std_tolerance} = \frac{0.0001}{0.000004} = 25$$



Example – Digital micrometer

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Micrometer and standard information.

Uncertainty Source	Standard Uncertainty inches (μm)	Confidence Level (%)	Type (A or B)	Distribution
Gage Blocks	0.000002 (0.0508)	95.00	B	Normal
Resolution	0.0000144 (0.3658)	100.00	B	Uniform
Environmental	0.0000001 (0.00254)	95.00	B	Normal
Random Error or Repeatability	0.0000083 (0.2108)	95.00	A	Student's t
Combined Uncertainty	0.0000168 (0.4267)			

$$\text{TUR} = \frac{\text{Upper} - \text{Lower}}{2 \cdot U_{95}} = \frac{0.0002}{2 \cdot 2 \cdot 0.0000168} = 3$$



Example – Analog micrometer

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Micrometer and standard information.

Parameter	Analog (Vernier) Micrometer 0-1 inch (0-25.4 mm)	Gage Block, Class 2
Tolerance	± 0.0001 inch (± 2.54 μm)	± 0.000004 inches (± 0.1016 μm)
Resolution	± 0.0001 inch (± 2.54 μm)	N/A

$$\text{TAR} = \frac{\text{UUT_tolerance}}{\text{Std_tolerance}} = \frac{0.0001}{0.000004} = 25$$



Example – Analog micrometer

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Micrometer and standard information.

Uncertainty Source	Standard Uncertainty inches (μm)	Confidence Level (%)	Type (A or B)	Distribution
Gage Blocks	0.000002 (0.0508)	95.00	B	Normal
Resolution	0.0000255 (0.6477)	95.00	B	Normal
Environmental	0.0000001 (0.00254)	95.00	B	Normal
Random Error or Repeatability	0.0000201 (0.5105)	95.00	A	Student's t
Combined Uncertainty	0.0000326 (0.8280)			

$$\text{TUR} = \frac{\text{Upper} - \text{Lower}}{2 \cdot U_{95}} = \frac{0.0002}{2 \cdot 0.0000326} = 1.5$$



Discussion of Results

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Neither example meets the 4:1 rule, but do they meet the 2% rule.

- At a KSC lab, the nomenclature “micrometer” has an overall EOPR of 96%.
- For the analog model number, the EOPR is 97.3%.
 - For a normal distribution, $k = 2.21$

$$CR(k, r, b) = \frac{1}{\pi} \cdot \int_k^{\infty} \int_{-r \cdot (k+t)+b}^{r \cdot (k-t)-b} e^{-\frac{(t^2+s^2)}{2}} ds dt \quad r = \frac{\sigma_x}{u_e}$$



Discussion of Results

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For the analog micrometer, use the EOPR data to solve for the value of σ_x and r

$$\sigma_x = \frac{0.0001}{2.21} = 0.0000452 \quad r = \frac{0.0000452}{0.0000326} = 1.387$$

$$\text{Consumer Risk: } CR(2.21, 1.387, 0) = 0.9\%$$

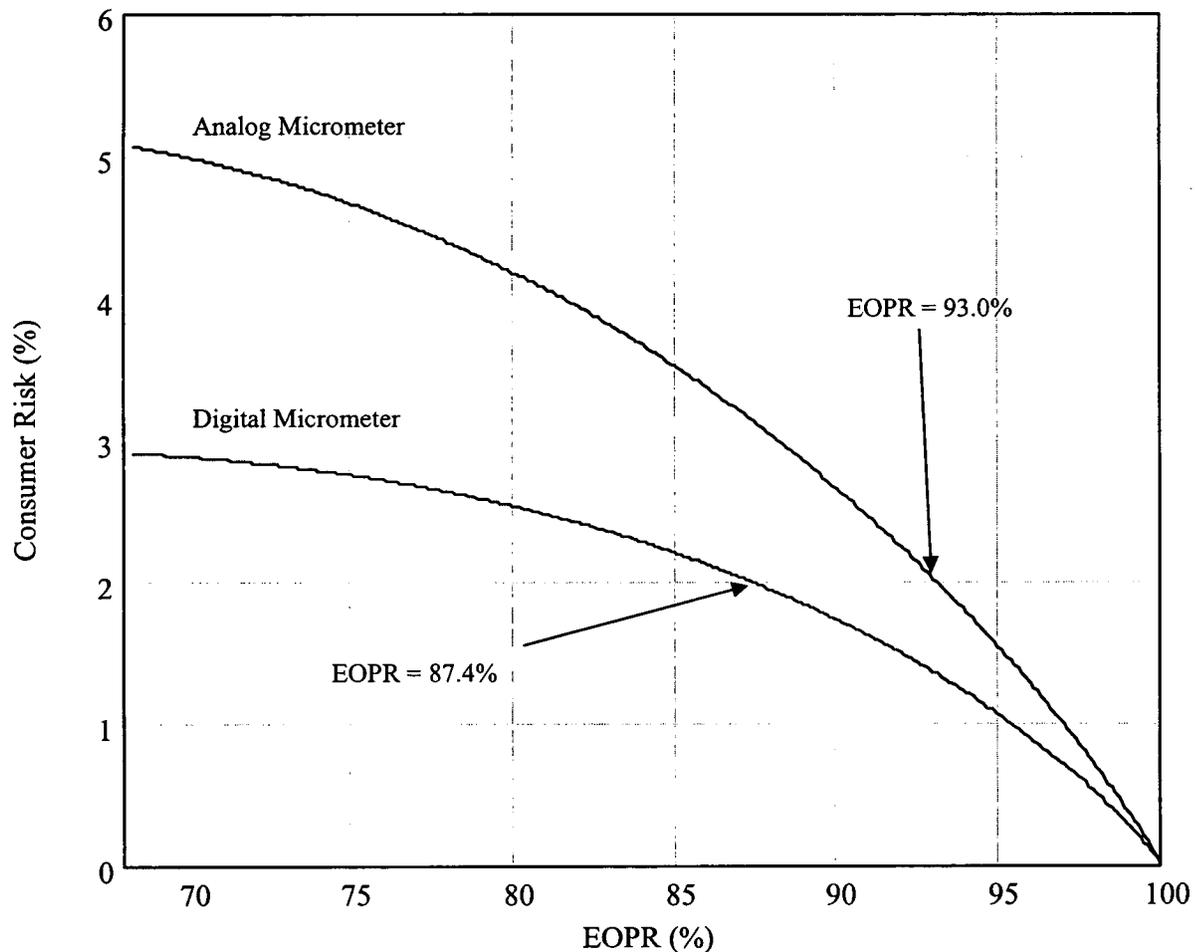
For an EOPR of 96%, the consumer risk = 1.3%.



Discussion of Results

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Consumer Risk over a range of EOPR values for both micrometers.





Summary and Conclusions

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- The TAR/TUR has been around for over 50 years
 - Originally intended to be temporary due to a lack of mathematical computing power
 - Various definitions have existed
- Z540.3 TUR is very different from earlier definitions
 - The denominator consists of *“the 95% expanded uncertainty of the measurement process used for calibration.”*
- Measurement Decision Risk analysis provide a high quality assessment of the calibration process.
- There are additional benefits to risk analysis, such as Producer Risk (False Reject) which can impact rework and product acceptance.

Definitions within requirements are important because...



Summary and Conclusions

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The devil is in the details.