Measurement Quality Assurance Principles and Methods

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Background

- *Historically, testing and calibration have been focused primarily on providing support for workload items in accordance with nominal requirements*
- *Little or no clear-cut relationship between the relevance of test or calibration results to the practical requirements of equipment users*
- *Each level of support has essentially been an isolated function, connected only by a thin thread of measurement quality traceability regulated by arbitrary criteria*

What is MQA?

- Measurement quality assurance evaluates and controls measurement quality through the application of scientific and mathematical principles and methods
- An integrated model that encompasses all phases of end item development and support
  - Measurement uncertainty analysis
  - Measurement decision risk analysis
  - Selection, interpretation and definition of equipment specifications
  - Calibration interval analysis and uncertainty growth modeling
  - Bayesian analysis for statistical measurement process control
  - Cost modeling and optimization

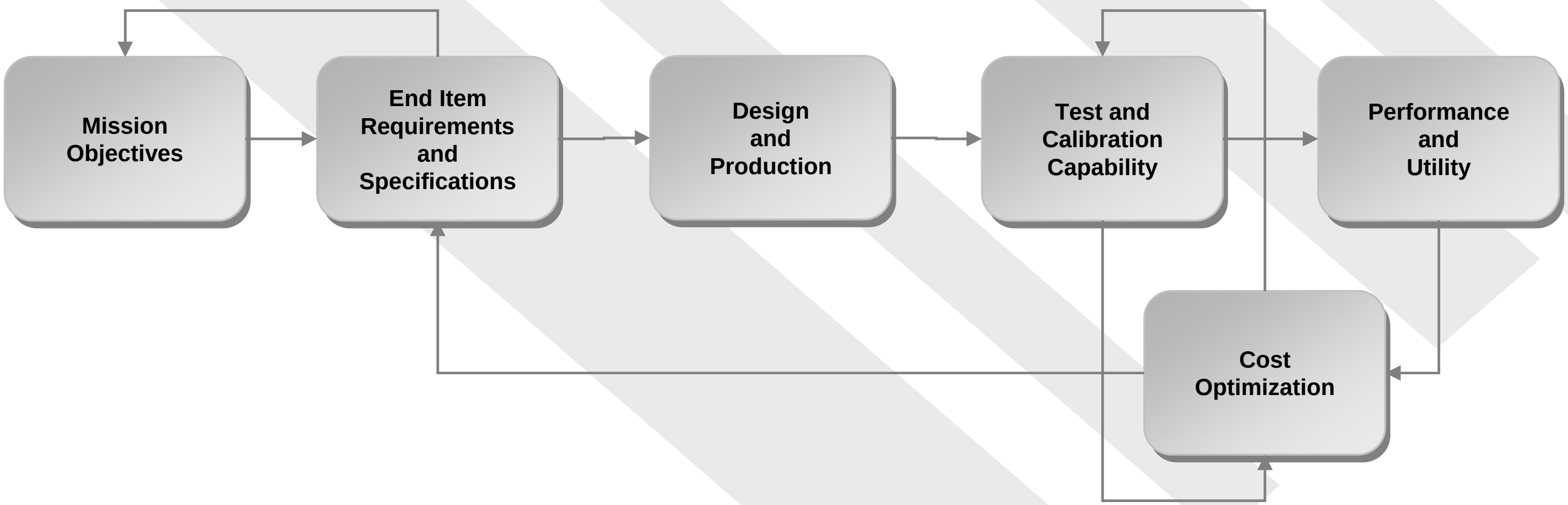
MQA "Products"

- *Assessment of whether activities, equipment, environments, and procedures involved in making a measurement produce a result that can be rigorously evaluated for validity and accuracy. Applied in*
  - *Design or selection of measuring and test equipment (MTE)*
  - *Development of measurement methods and procedures*
  - *Design and evaluation of research studies and experiments*
  - *Acceptance testing decisions*
  - *Analysis of MTE calibration and support*
  - *Total cost optimization*

MQA Benefits

- *Improved measurement processes that ensure the best available data for making decisions*
  - *Cost-effective and timely development and deployment of new technologies*
  - *Rigorous assessment of commercial off-the-shelf equipment*
  - *Application of existing technologies for current and future programs and projects*

MQA End-to-End



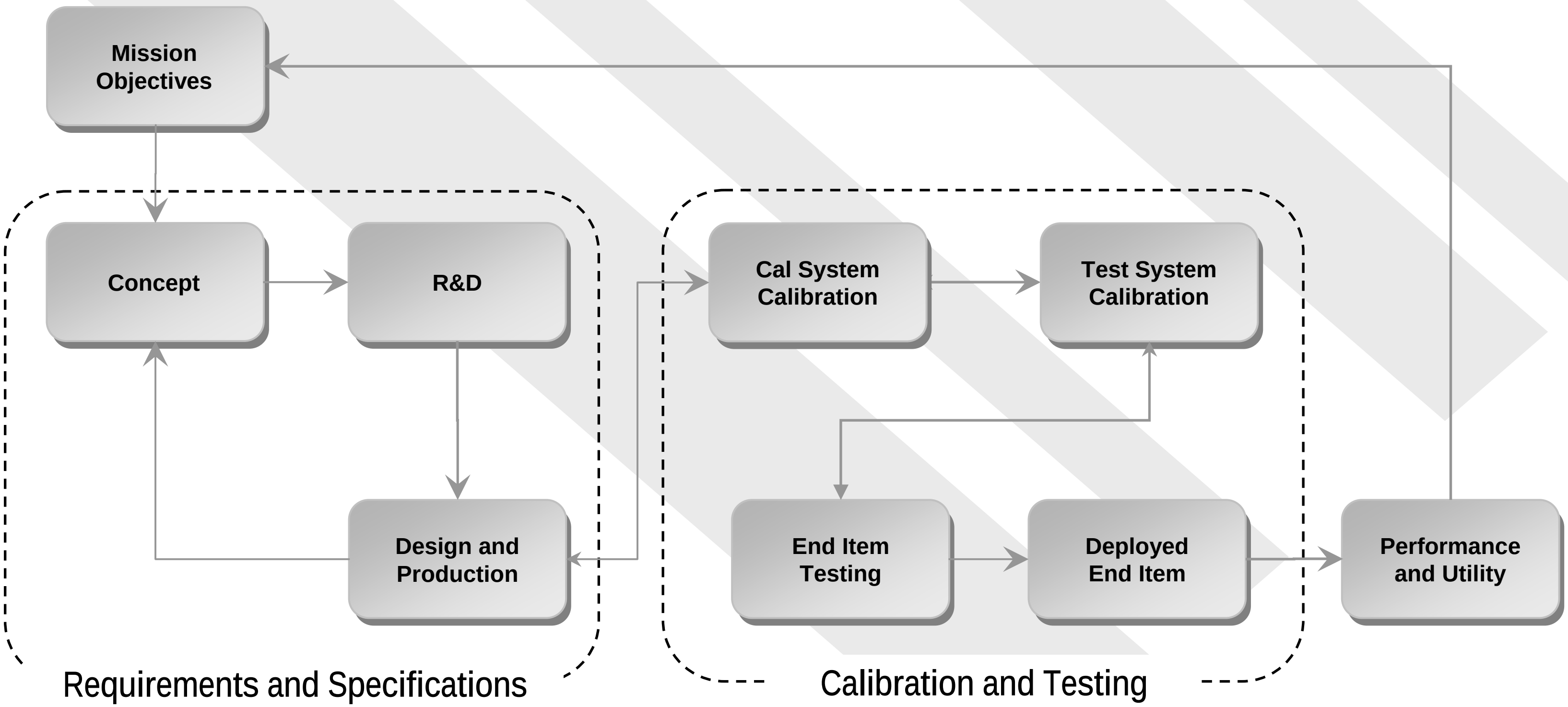
The MQA End-to-End Approach

Integrating MQA in all Phases of End Item Development, Support and Operation

The End-to-End MQA Support Sequence

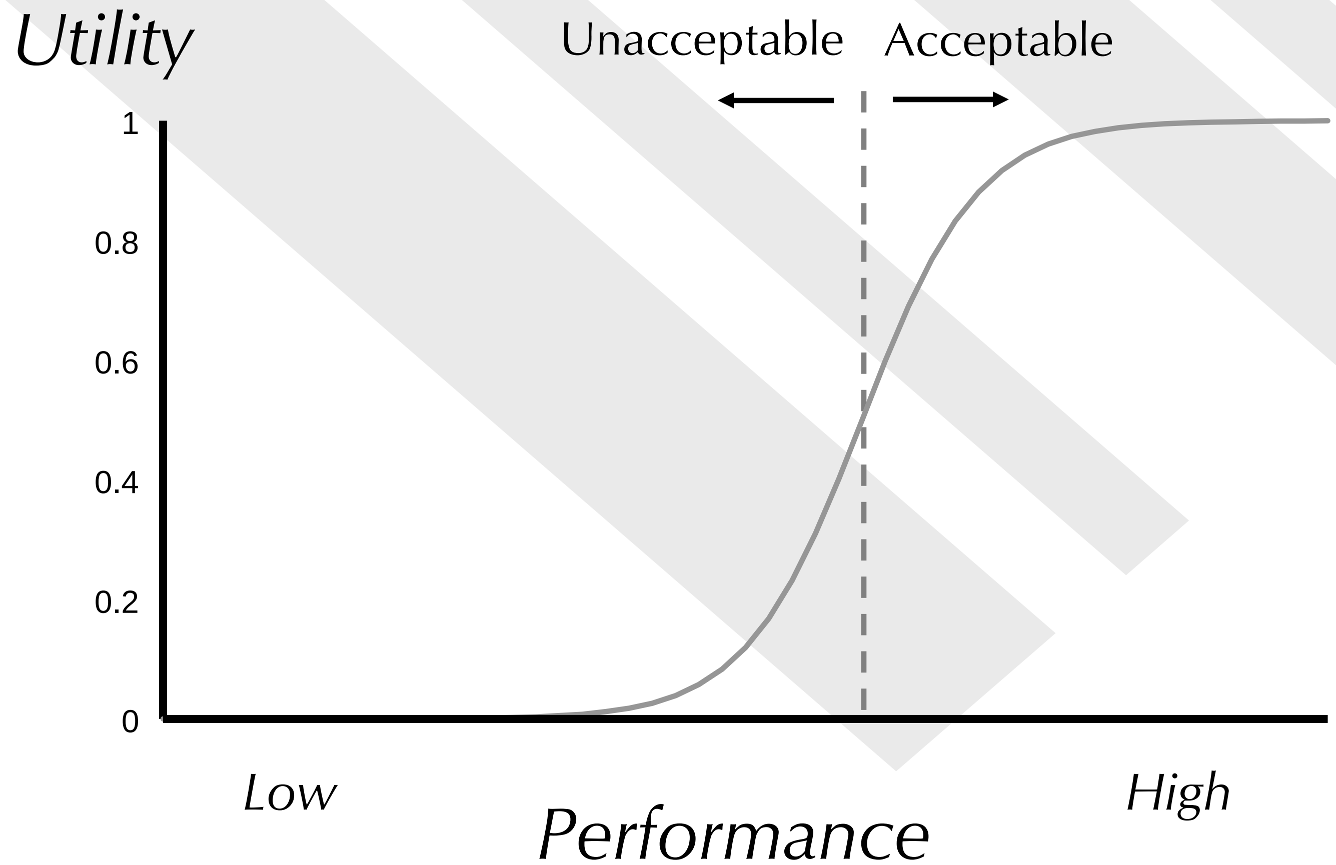
- Concept studies
- R&D
- Design and production
- Testing and calibration
  - Calibration system calibration
  - Test system calibration
  - End item testing
  - End item performance monitoring

The End-to-End MQA Support Sequence (cont.)

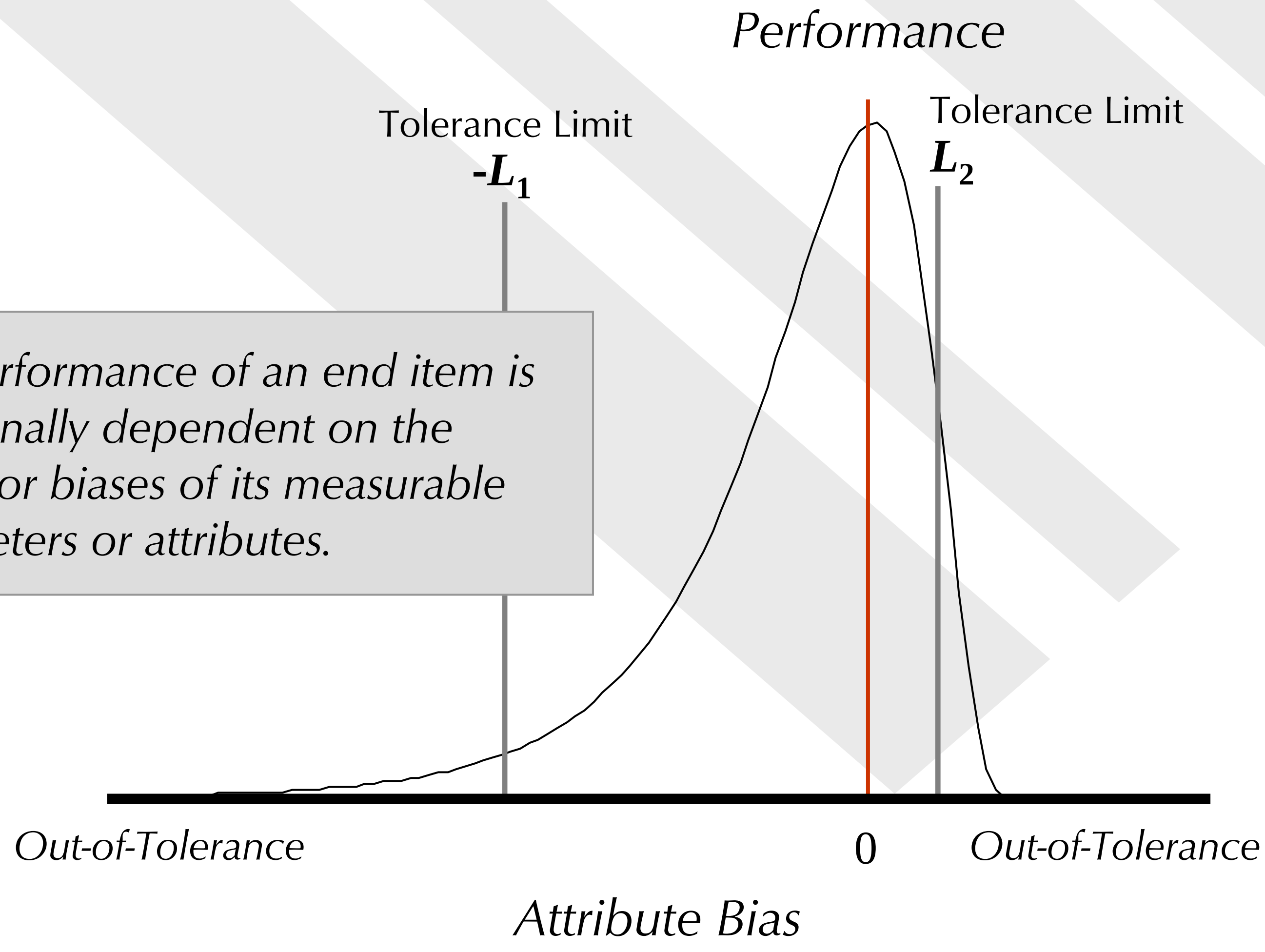


Performance objectives drive requirements.
Support capability tempers requirements.

End Item Performance and Utility



Performance and Attribute Value



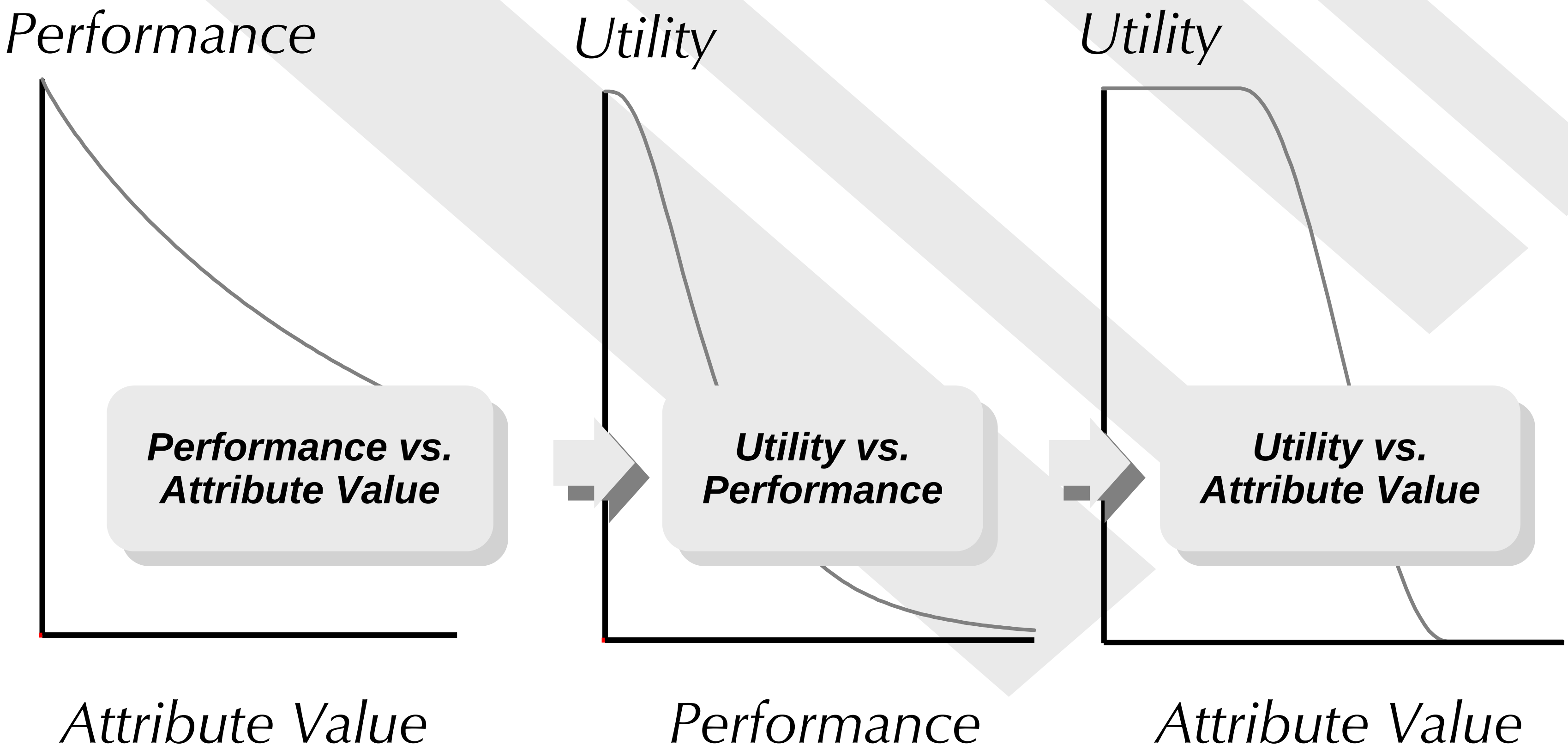
The performance of an end item is functionally dependent on the values or biases of its measurable parameters or attributes.

Utility and Attribute Value

- *If end item utility depends on end item performance, and ...*
- *End item performance is a function of attribute values, then ...*
- *End item utility is a function of attribute values.*

Utility and Attribute Value

Establishing the Link



Why do this?

- We want to know how the values of the attributes we're designing, building and testing relate to the utility of the end items they comprise.
  - Determine the limits attribute values must be contained within and the probability of containment needed to achieve a given level of utility.
  - Determine the cost benefit of this level of utility.
  - Determine what it costs to achieve the attribute value containment.
  - Balance this cost against the benefit of the utility gained by the attribute value containment.

Utility and Uncertainty

- *Calibration support is established to ensure that test system attribute values are in-tolerance during end item testing.*
- *The more accurate the calibration, the greater the assurance of in-tolerance test system attributes.*
- *The more accurate the calibration, the greater the assurance of in-tolerance test system attributes.*
- *The greater the assurance of in-tolerance test system attributes, the greater the assurance of in-tolerance end item attributes.*
- *The greater the assurance of in-tolerance end item attributes, the greater the assurance of acceptable end item utility.*

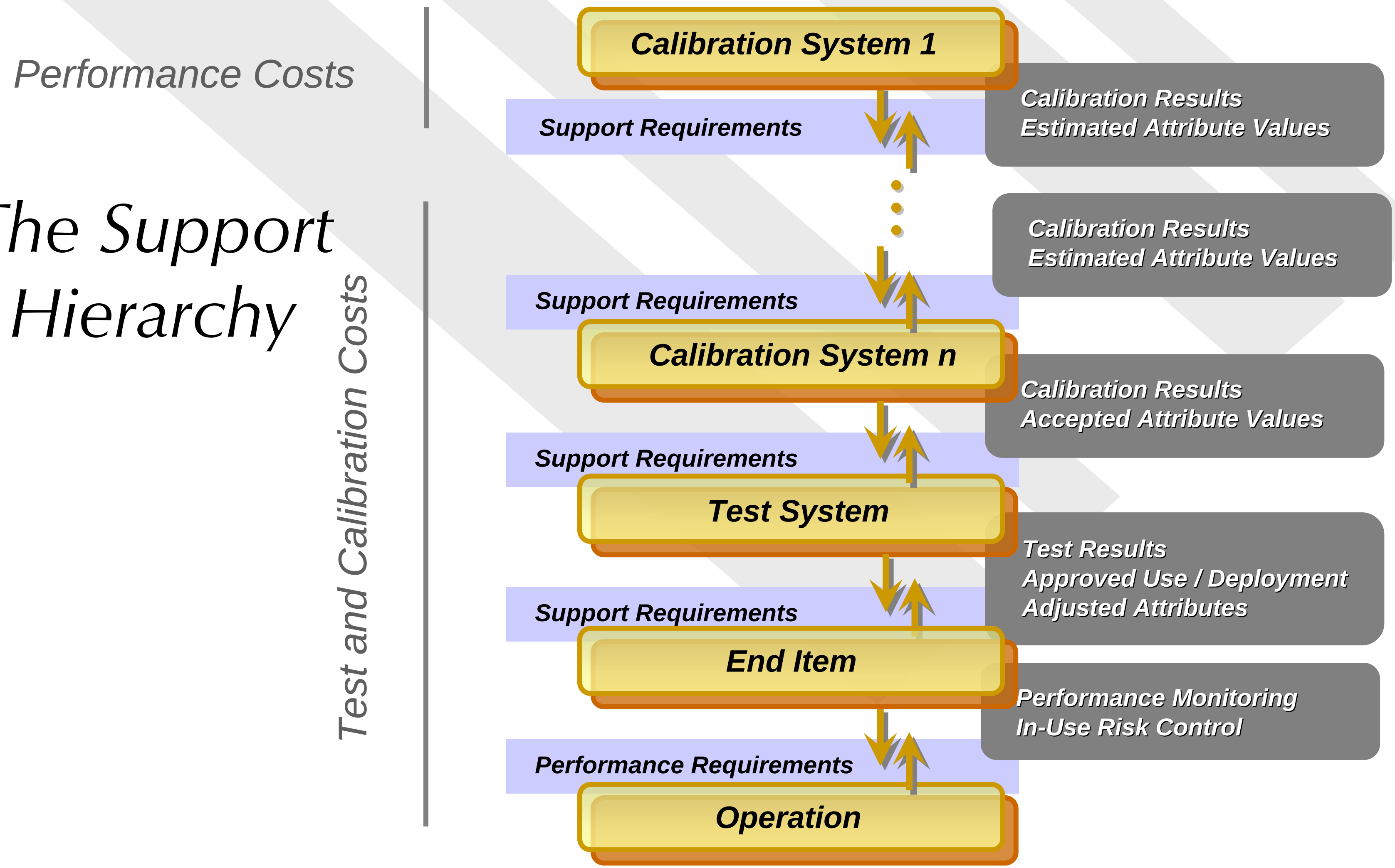
Utility and Uncertainty

Uncertainty vs. Costs

- *Low utility means high costs associated with end item operation. This cost element is referred to as **performance cost**.*
- *Accurate calibration and testing promote high end item utility.*
- *Conclusion: Money spent on controlling testing and calibration measurement process uncertainty yields a return on investment in lower end item performance costs.*

Test and Calibration Support Hierarchy

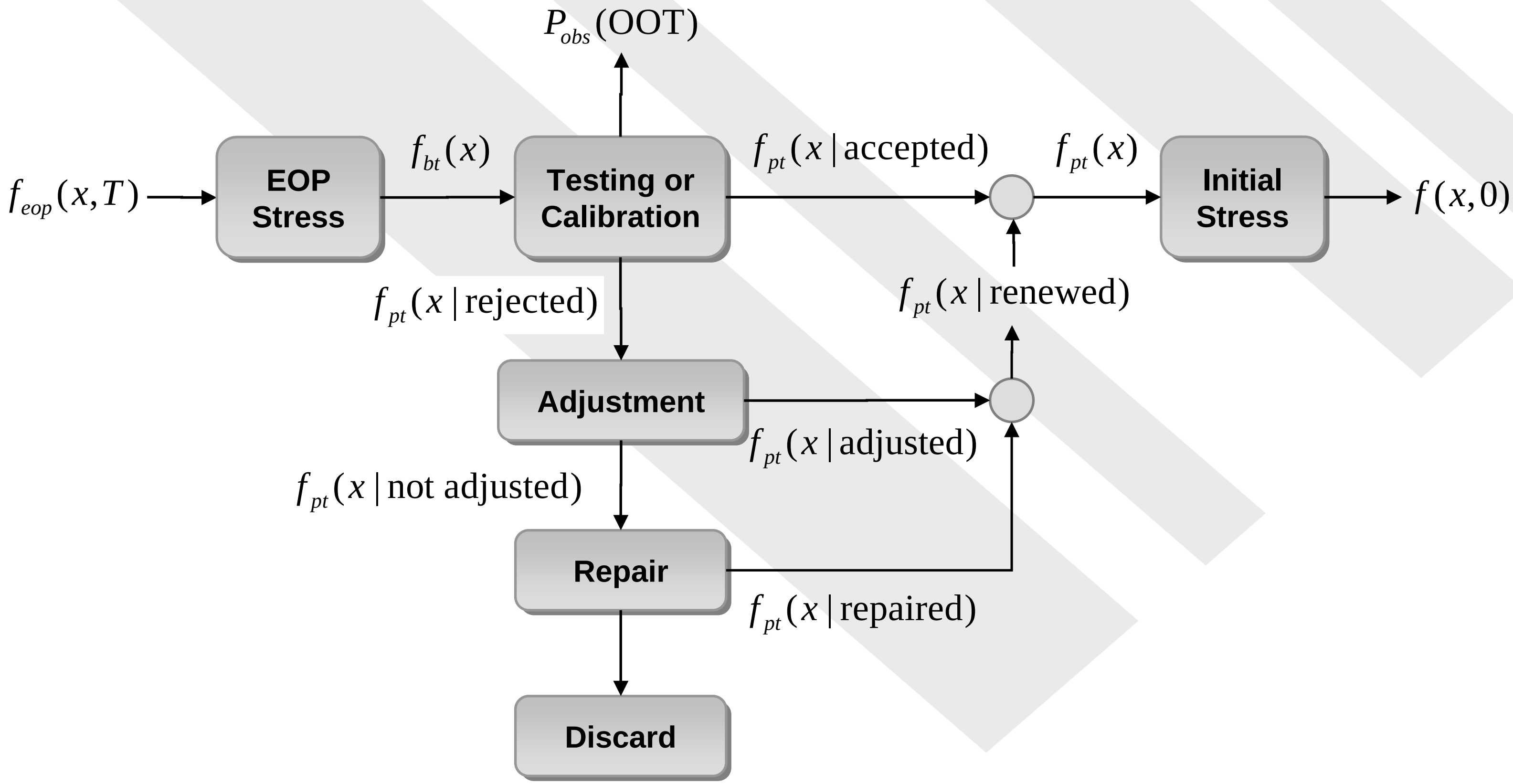
The Support Hierarchy



Uncertainty Propagation

Calibration Standard	Calibration System	Test System	End Item Operation
	▸ Calibrated Cal System ▸ Reported Value or Bias	▸ Calibrated Test System ▸ In-Tol or OOT Finding	▸ Tested End Item ▸ Test Report
Cal System Calibration → ••• →	**Test System Calibration** →	**End Item Testing** →	**Accepted End Item**
▸ Reference Standard Bias ▸ Measurement Process Uncertainties	▸ Cal System Bias ▸ Measurement Process Uncertainties ▸ Measurement Decision Risks	▸ Test System Bias ▸ Measurement Process Uncertainties ▸ Measurement Decision Risks	▸ End Item Attribute Bias ▸ Bias Uncertainty ▸ Measurement Reliability ▸ Utility

Uncertainty Propagation Across Levels



Cost Optimization

- Life Cycle Cost Elements C_s
  - Ownership
  - Acquisition
  - Training
  - Disposal
- Performance Cost C_p
- Total Cost

$$C_{total} = C_s + C_p$$

Support Cost

The test and calibration support cost model is expressed as

$$C_s = C_{cs}^{cal} + C_{ts}^{cal} + C_e^{test}$$

where

C_{cs}^{cal} = *the total cost of calibrating the calibration system inventory*

C_{ts}^{cal} = *the total cost of calibrating the test system inventory*

C_e^{test} = *the total cost of testing the end item inventory*

Performance Cost Elements

- Failed missions - The direct cost of an end item failing to perform successfully in combat.
- Wasted hardware - The cost of ordnance or other hardware expended unsuccessfully.
- Injury or loss of life - The cost of casualties incurred due to unsuccessful performance.
- Recall and retrofit - The cost of reworking systems that fail to meet performance expectations.
- Penalties - Fines, levies or other penalties resulting from unsuccessful end item performance.
- Warranty expenses - The cost of honoring warranties for unacceptable end item performance.
- Legal Fees - The cost of legal actions resulting from unacceptable end item performance.
- Lost Income - Income lost due to unacceptable end item performance.
- Loss of reputation - The cost of lost future business and/or public relations costs incurred in overcoming public reaction to unacceptable end item performance.

Performance Cost Variables

- Cost of Zero End Item Utility
- Quantity of End Items in Use
- End Item Acquisition Cost
- Encounter Probability
- Successful Response Probability

Performance Cost

- *The cost incurred if an end item is used in a specific situation*

$$C_p = C_u N_{ps} P_e,$$

where

C_u	=	*the cost of utility for an end item attribute*
N_{ps}	=	*the number of end items in use*
P_e	=	*the encounter probability*

Utility Cost

$$C_u = C_{fail}\left[1 - \frac{P_{success}}{T}\int_0^T \int_{-\infty}^{\infty} f(x,t)\,u(x)\,dx\,dt\right]$$

where

C_{fail} = *cost of zero utility*

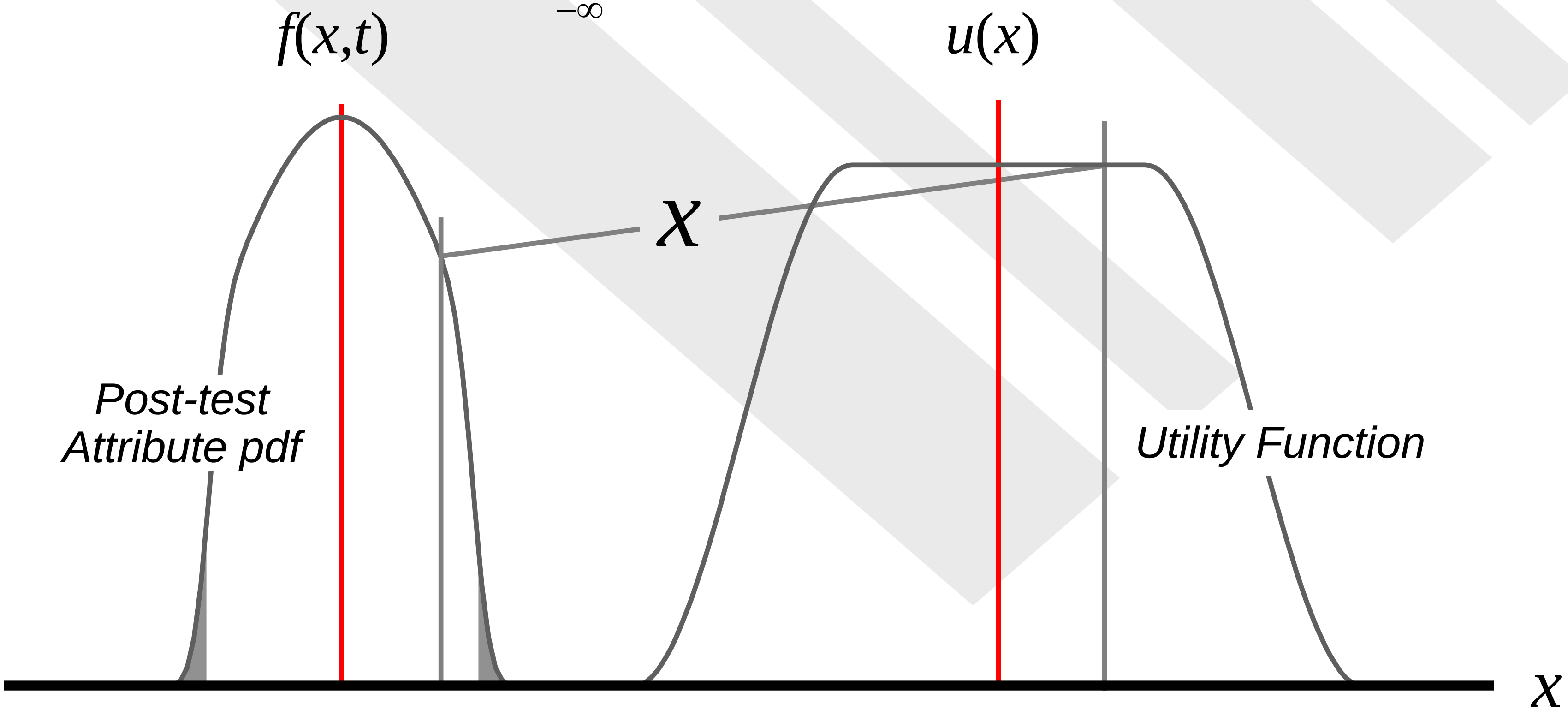
$f(x,t)$ = *end item attribute in-use pdf*

$u(x)$ = *end item utility function*

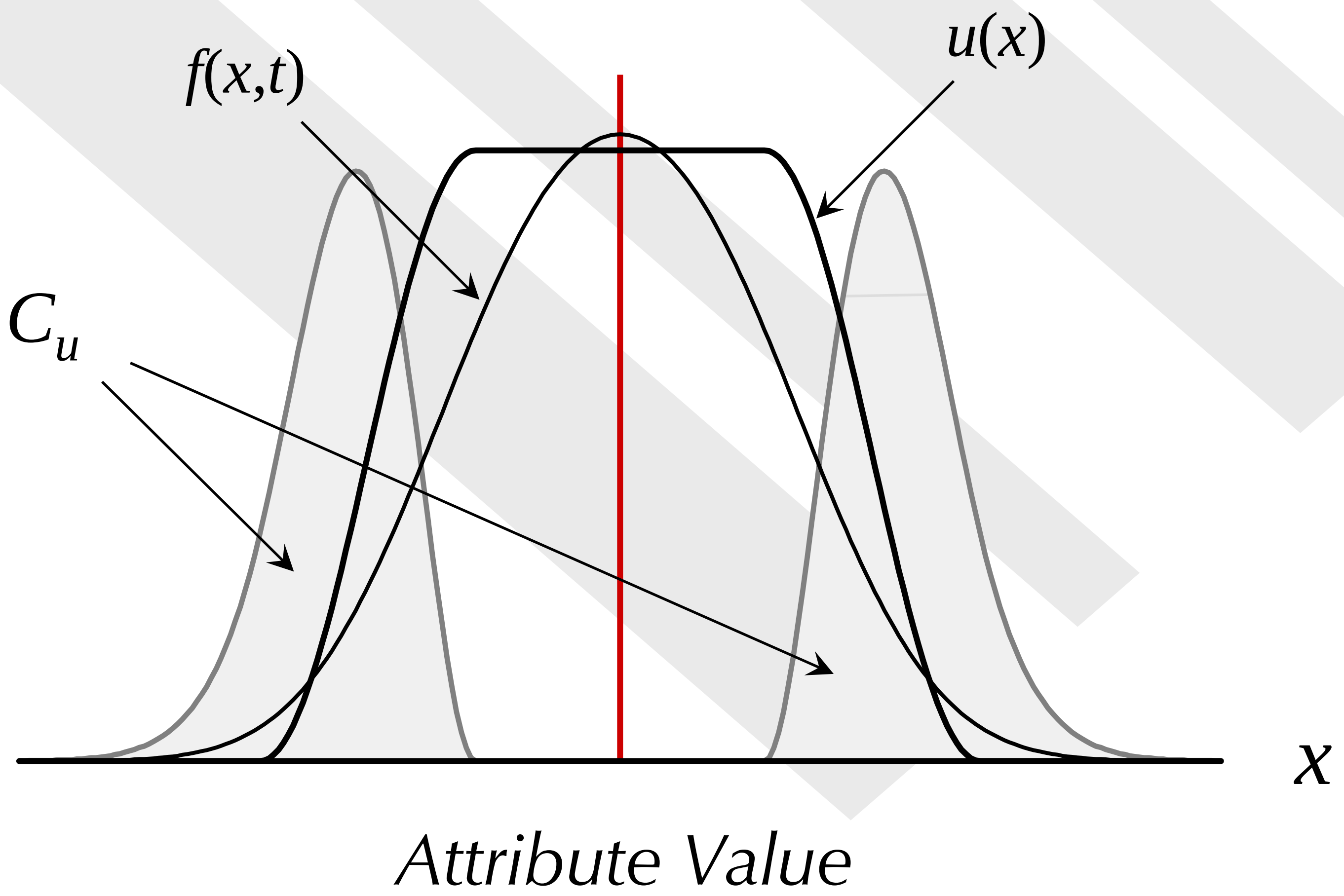
$P_{success}$ = *probability of successful performance*

Utility Cost Integral

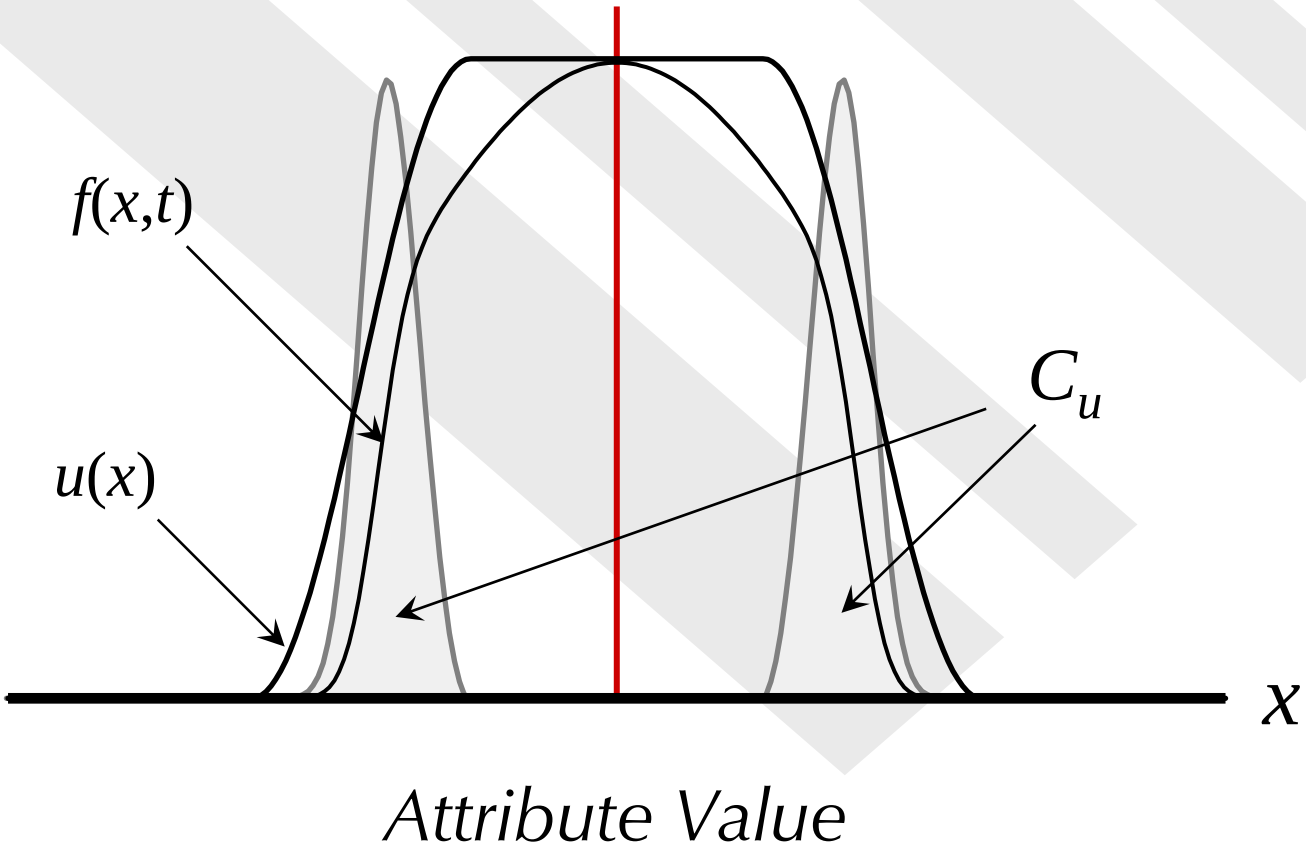
$$\int_{-\infty}^{\infty} f(x,t)u(x)dx$$



Utility Cost Estimate – High Uncertainty



Utility Cost Estimate – Low Uncertainty



Current State of MQA Development

- General Analytical Metrology Research and Development
- NASA-HNBK-8739.1-9
  - Encompasses all MQA areas and methods
  - Under development
- NCSLI RPs
  - Under development and update
- Equipment Tolerancing System (ETS)
  - DOS application
  - Undergoing expansion, revision and conversion to Windows
- Various Software and Freeware Applications

Useful References

- *All disciplines*
  - *JPL, Metrology – Calibration and Measurement Processes Guidelines, NASA Reference Publication 1342, June 1994*
  - *NASA, Measurement Quality Assurance Handbook, National Aeronautics and Space Administration, NASA-HDBK-8730.19, In-Progress*

Useful References (cont.)

- *Uncertainty Analysis*
  - *ISO/IEC, Guide to the Expression of Uncertainty in Measurement, Guide 98-3, 1995*
  - *ANSI/NCSL Z540-2-1997 (R2002), U.S. Guide to the Expression of Uncertainty in Measurement (ISBN 1-58464-005-7), October 1997*
  - *NCSLI, Determining and Reporting Measurement Uncertainties, Recommended Practice RP-12, NCSL International, Under Revision*

Useful References (cont.)

- Measurement Decision Risk Analysis
  - NCSLI, Estimation and Evaluation of Measurement Decision Risk, Recommended Practice RP-18, NCSL International, In-Progress
  - ASME, Measurement Uncertainty and Conformance Testing: Risk Analysis, ASME B87.7.4.1, 2005
  - NCSLI, Handbook for the Application of ANSI/NCSL Z540.3, In-Progress

Useful References (cont.)

- *Calibration Interval Analysis and Uncertainty Growth Modeling*
  - *NCSLI, Establishment and Adjustment of Calibration Intervals, Recommended Practice RP-1, NCSL International, Under Revision*
- *Equipment Specifications*
  - *NCSLI, Interpreting and Applying Equipment Specifications, Recommended Practice RP-5, NCSL International, In-Progress*

Useful References (cont.)

- Cost Modeling and Optimization
  - JPL, Metrology – Calibration and Measurement Processes Guidelines, NASA Reference Publication 1342, June 1994
  - NASA, Measurement Quality Assurance Handbook, National Aeronautics and Space Administration, NASA-HDBK-8730.19, In-Progress