Models for Digitalized Measurement Data

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Section 1

Introduction

Today's topics

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1. Introduction
2. Conceptualize, model, implement

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3. Draft models

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3. Draft models
4. Conclusion

Learning objectives

Those who see the presentation and read the paper should gain

1. a big-picture view of NCSLI's digital-transformation efforts;
2. some appreciation for conceptual models and their applications in digital transformation;
3. a glimpse of the business value in digitalized measurement data.

Acronyms

- IQI—international quality infrastructure
- MRA—mutual-recognition agreement
- CIPM—International Committee on Weights and Measures
- NMI—national metrology institute
- KCDB—key-comparison database
- ILAC—International Laboratory Accreditation Cooperation
- AB—accreditation body
- SoA—accreditation scope
- CMC—calibration and measurement capability
- Digital Transformation (DX)
- MPE—maximum permissible error
- DCC—digital calibration certificate
- DCR—digital calibration request
- FAIR—findable, accessible, interoperable, reusable
- M-layer—metrology information layer to support measurement systems
- JSON—JavaScript object notation
- XML—eXtensible markup language
- MathML—mathematics markup language

Section 2

Conceptualize, model, implement

DX reality

Facts

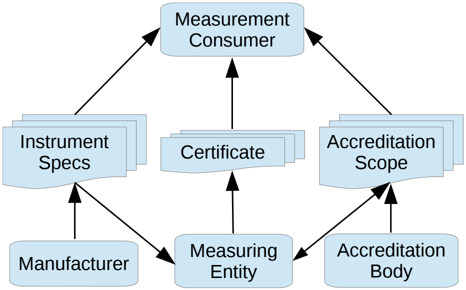
- Business thrives to the extent that customers receive positive net value.
- DX provides new value at lower cost: finance, B2B, online retail, travel, entertainment
- Metrology has consensus standards, plentiful computing power, lab and enterprise software, automated measurements and plenty of applicable information technologies.
- Despite resources and long-standing development, metrology has not yet achieved DX.

Success Factors: Other industries achieved DX by

- Carefully abstracting their processes and data flows
- Modeling the supporting data
- Applying standardized technology solutions to implement those models in digital systems

Translating DX success to metrology

1. Metrology processes revolve around measurements and their quality.
2. Measurement data doesn't sit ignored; calibration laboratories, testing laboratories, inspection bodies, instrument manufacturers, ABs, scientific organizations and others exchange the data in vast quantities throughout the measurement economy.
3. To digitally transform metrology, we should therefore design, adopt and apply a common conceptual model for exchanging digitalized measurement data.



Conceptualize, model, implement!

Modeling costs

Modeling takes resources and time

- Modeling delays implementation and any expected revenue or savings.
  - Conceptual models require much careful abstract thought and refinement.
  - Models should cover all known process and feature variants within scope.
- Tooling for modeling leaves gaps.
  - No complete end-to-end system for all environments
  - Piecewise solutions: model-driven architecture, model-driven software engineering, object relational modeling, model-view-controller technology

Forget flying birds, just build a penguin!

- DCC: fast development, much interest, tough to use
- Implementation may fragment into separate cases that do not integrate well.
- Everyone reinvents the wheel for every case.

Conceptual modeling benefits

General benefits

- Agnosticism: no particular storage or transmission technology baked in
- Universal interoperability and reusability

Benefits for metrology

- Locate and rank laboratories to calibrate a given instrument or inventory.
- Locate and rank instruments to meet an application's measurement requirements.
- Generate customized instrument specifications or DCRs and issue purchase orders.
- Generate CMCs from instrument specifications and calibration certificates.
- Optimize instrument specifications or calibration intervals from calibration history.
- Generate automated, customized calibration procedures on the fly.
- Improve uncertainty estimates flowing through the traceability network.

Conceptual modeling benefits

- Recover lost value from over-simplified MPEs, CMCs and measurement uncertainties.
- Validate certificate uncertainties against accreditation scopes.
- Verify accreditation status and compliance to calibration requirements point-by-point.
- Verify an AB's ILAC MRA or an NMI's CIPM MRA status.
- Automate non-conformance investigations.
- Calculate uncertainty, risk, reliability, et al. between and beyond calibration points.
- Propagate calibration uncertainties to all dependent test & measurement processes.
- Correct all measurements for instrument bias (transparent adjustments).
- Facilitate digital twins and smart instruments.
- Streamline assessments and audits.
- Validate all data automatically at every step.

Conceptual modeling benefits

Caveats

- The market will determine where the real value lies.
- Innovators will expand this list far beyond what we might predict.
- The benefits remain a pipe dream without interoperability.
  - Benefits stem from lowering the data-exchange hurtles between organizations.
  - Machines should exchange and process this data automatically.
  - If a pressure implementation differs from that of voltage, length or radiance, those multiple disjoint cases quickly burden software implementations, a significant development and maintenance cost that every software developer will suffer.
  - Since we already expect to ultimately transform the entire IQI—all measurement processes and quantities—it makes sense to model measurements generally, abstractly, from the start and to expect a higher return.

Section 3

Draft models

General model requirements

Interoperability and reusability (objectivity) require source-independent meaning and validity:

1. correct reasoning—well designed data & process models for the present and future,
2. data transformed to a standardized context—reference metadata and unique identifiers,
3. correct formulation—standardized meanings, (linked) definitions, controlled syntax;

AND freedom from subjectivity such as

1. arbitrariness—undefined or free-form data fields,
2. ambiguity—multipurpose data fields, missing unique identifiers, unclear definitions,
3. out-of-context placement—essential elements falling outside the modeled framework.

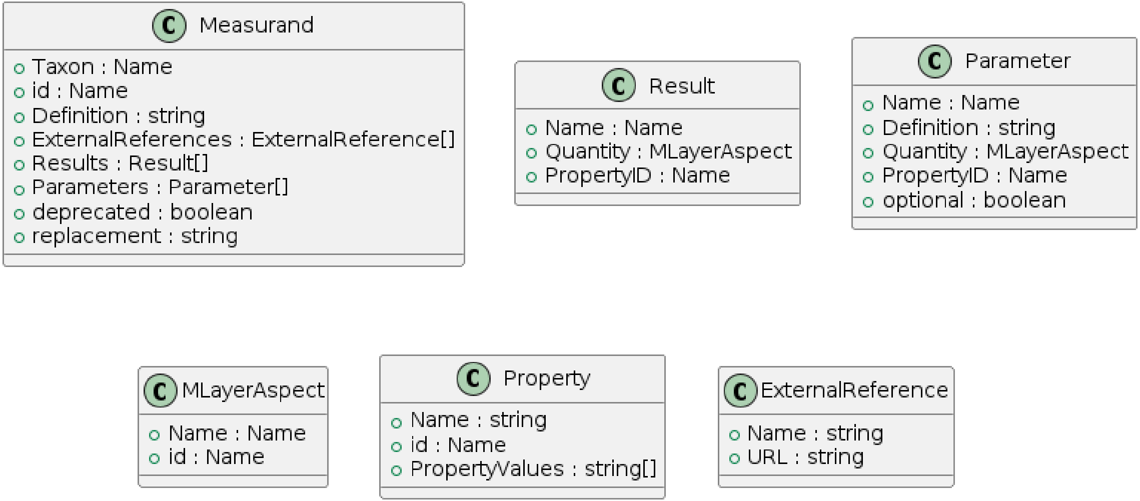
Metrology model requirements

Metrology DX requires an flexible, exacting, universal measurand model.

- Measurand: What an instrument measures, what we claim capabilities for, what we measured in a calibration or other measurement service.
- Universal: Abstract enough to cover any quantity, property, discipline or area
- Exacting: Perfection commensurate with the uncertainty desired in specifying the quantity, its influence quantities, relevant properties and operating conditions
- Flexible: Unlimited, exacting measurand qualifiers, omitted when insignificant relative to the measurement uncertainty or irrelevant to the service procured

All together this means we want an abstract model that distinguishes any measurand which anyone may instantiate with only the relevant detail for a particular concrete application.

Abstract measurand model (essential elements only)



Differentiating parameters

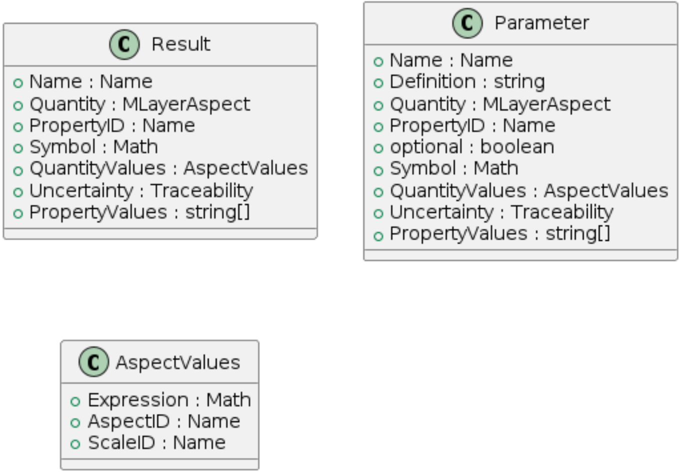
Model Element	Instrument Measurand		CMC Measurand
`Measurand.Taxon`	"Source.Ratio.Voltage.AC"	⇔	"Measure.Ratio.Voltage.AC"
`Result.Name`	"Gain"	⇔	"Gain"
`Parameter.Name`	"Frequency"	⇔	"Frequency"
`Parameter.Name`	"InputVoltage"	⇔	"InputVoltage"
`Parameter.Name`	"OutputVoltage"	⇔	"OutputVoltage"
`Parameter.Name`	not used (optional)		"AmbientRH"

Matching parameters between different instantiations of an abstract measurand. The two measurands match, pending further evaluation of measuring intervals and uncertainty requirements.

Concrete measurand model (essential elements only)

The concrete data model

- Adds value, range, uncertainty
- Covers specs, CMCs, measurement results
- M-layer: any property, quantity, scale type, unit
- Math expressions for generality
  - any number (x)
  - symbols ($q = x$)
  - ranges ($L \leq q < H$)
  - complexities ($L \leq Vf \leq H$)
  - interdependence ($V_1 < V_2 < 2V_1$)



Open modeling questions

- Abstractly, expression model = mathematics
- Concretely, MathML content markup would work for expressions but presupposes XML.
- The `Uncertainty` : `Traceability` element awaits further work to cover
    - simple uncertainty expressions
    - various uncertainty representations and propagation methods
    - a representation of the entire traceability network
- Previous work covers all this but requires integration.
- Traceability chains would help document and maintain CMCs and MPEs also.

Modeling progress

- See GitHub (github.com/NCSLI-MII/measurand-taxonomy) for the latest actual info.
- The committee's model may vary from this conception.
- The actual model includes other niceties: measurement category and discipline, mappings to other quantity systems, etc.
- Currently documenting and populating the M-layer
- Working toward an official release of the measurand catalog (taxonomy)
- Fall 2025 Webinar
  - Second annual NCSL International Quality Infrastructure Modeling Workshop
  - Focus on applications and training: taxonomy, measurands, M-layer

Section 4

Conclusion

Conclusion

- A common conceptual model for exchanging digitalized measurement data will power metrology's digital transformation.
- Standardized reference metadata sets with a universal reference model for measurement data provides interoperability to aids application software to streamline the IQI.
- This in-progress model suffices to start using the measurand taxonomy to identify and exchange interoperable data.
- Unanticipated realities will arise, requiring agile conceptualize-model-implement iterations.

Acknowledgments

Please see the paper for further detail.

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And Thank You for your time!

Questions?