NCSLI 141 MII and Automation Committee

First Annual NCSLI Quality Infrastructure Modeling Workshop

July 11, 2024

2024 NCSL International & Conference on Precision Electromagnetic Measurements Workshop & Symposium

First Annual NCSLI Quality Infrastructure Modeling Workshop

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NCSL International 141 MII and Automation Committee

Section 1

Welcome

Section 2

Introduction

Many thanks to

Organizer and Developer

- Ryan White

NCSLI Support

- Andrew Oldershaw
- Rob Knake
- NCSLI Conference Committee
- NCSL International 141 MII and Automation Committee
- Georgette Macdonald

All Participants!

Speakers

- Mike Brown
- Anna Cypionka
- Heidi Foldal
- Jeff Gust
- Rob Knake
- Mark Kuster
- Andrew Oldershaw
- Mike Schwartz
- Ryan White

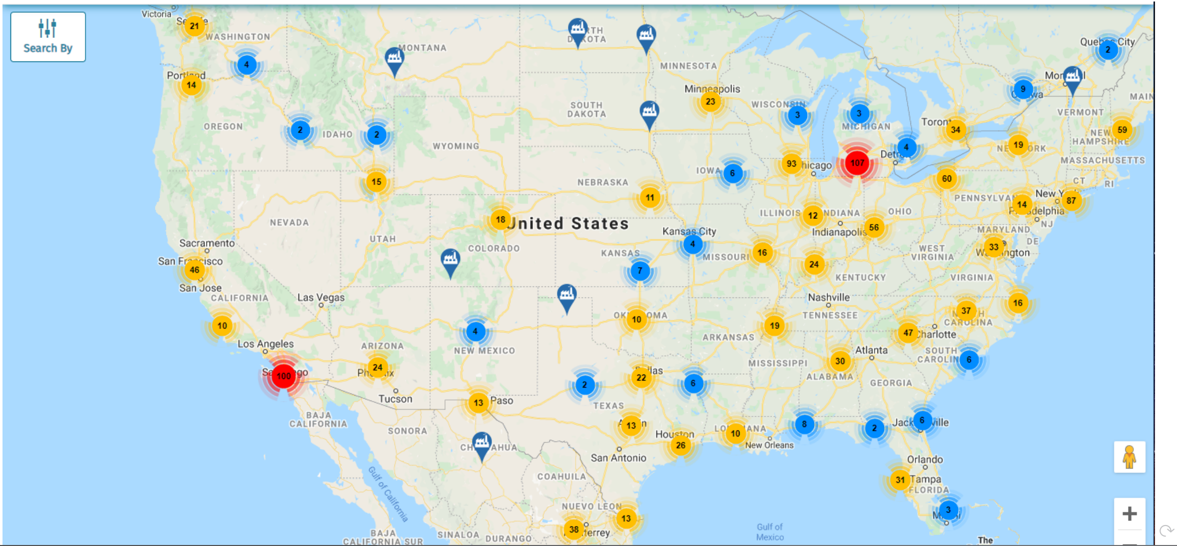
NCSL International 141 MII and Automation Committee History

- 2013: Began thinking seriously about digitalizing metrology
- 2013: *Metrologist* column: "Toward a Measurement Information Infrastructure"
- 2015: Developed a strategy, started conceptual demonstration projects and collaborations
- 2017: Reformulated the Automation Committee to focus on MII development
- 2023: NCSLI President Georgette McDonald signed the Joint Statement of Intent on DX
- 2024: First Annual NCSLI Quality Infrastructure Modeling Workshop
- For further information see `http://miiknowledge.wikidot.com/`

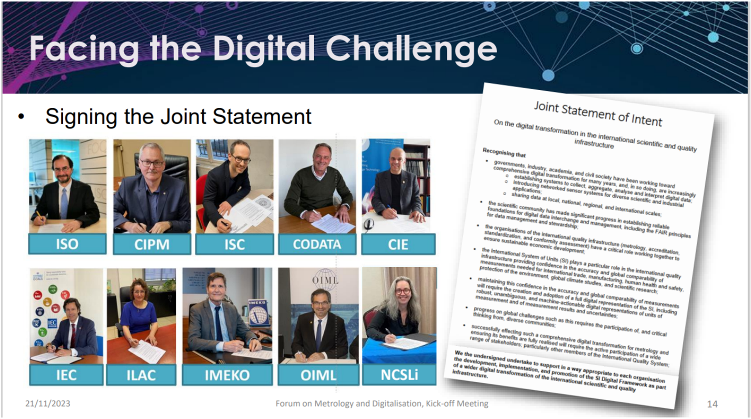
MII Products

- High-level unified data models for all measurement-data documents
  - XML schema, editor and concept proofs for accreditation scopes
  - Building technology-agnostic models on GitHub
- Demonstrations such as Qualer Search
- M-Layer: fundamental digital representations for quantities, scales and units
  - Prototype registry and API established
  - mlayer.org, GitHub repository
- Measurand metadata taxonomy for digital-document interoperability
  - Example: `Measure.Pressure.Pneumatic.Gage.Static`
  - BIPM would like the taxonomy linked to its service categories.
  - Currently expanding the taxonomy for full KCDB CMC coverage
  - GitHub repository established for collaboration

Demonstrated value



Joint Statement of Intent on DX in the IQI



Courtesy of Joachim Ullrich, 2023 Forum-MD Chair

Theme: Conceptualize, Model, and Implement

The range of JSI Signatories exemplifies the breadth of modeling required.
The depth of modeling extends from high-level processes & data to low-level fundamentals.

Processes

- mutual recognition
- assessment and accreditation
- conformance acceptance

Quality documents

- certificates
- accreditation scopes
- instrument specifications

Information

- traceability & uncertainty
- CMCs
- measurement functions
- measurement results
- requirements (e.g., MPEs)
- quantities & properties
- units & scales

Overview

1. Welcome
2. Introduction
3. CIPM Forum on Metrology and Digitalization and the SI Digital Framework
4. Model-driven software development and Metrology Model applications
5. Break
6. Introduction to CATWOE analysis and stakeholder perspectives to digital transformation
7. Collaborative activity—Metrology model application ideation
8. Building robust digital descriptions of measurement capabilities
9. Demonstration—Metrology metadata applications
10. Lunch
11. Data management principles at industrial calibration labs
12. Digitalization of Device Specifications
13. Discussion—Accreditation and Conformance Assessment Measurement Classifications
14. Break
15. Digitalization from the perspective of instrument manufacturers—challenges to deliver digital calibration certificates
16. Collaborative Activity—Identifying and structuring manufacturer specifications, accredited measurement capabilities, and certificate calibration data
17. Demos, Open Discussion
18. Closing Remarks

Section 3

CIPM Forum on Metrology and Digitalization and the SI Digital Framework

Section 4

Model-driven software development and Metrology Model applications

Section 5

Break

Section 6

Introduction to CATWOE analysis and stakeholder perspectives to digital transformation

Section 7

Collaborative activity—Metrology model application ideation

Section 8

Building robust digital descriptions of measurement capabilities

Theme: Conceptualize, Model, and Implement

- Conceptualize
  - Step back from current practice.
  - Return to metrological concepts and rethink implementation.
  - Ask why, why, why; don't emulate.
- Model
  - Model in reusable modular pieces.
  - Focus on abstractions (integrated essentials)
  - that unite concrete differences (pressure as against voltage).
  - Use FAIR reference data.
- Implement: Customer use cases
  - What problems do we solve?
  - What value does a digital solution add?

Rethink processes

- Expose pragmatic assumptions underlying manual practices.
- Root out shortcuts, avoided work, sub optimum quality.
- Examples: Why
  - buy from familiar equipment and service vendors?
  - round off measurement results and uncertainties?
  - choose simple uncertainty distributions (rectangular)?
  - interpret specs simply (all 95 % confidence)?
  - ignore correlation and degrees of freedom?
  - generate "conservative" uncertainties?
  - test and report only at minimal points?
  - curtail information on calibration certificates?
  - apply tolerances (MPEs) and decision risk?

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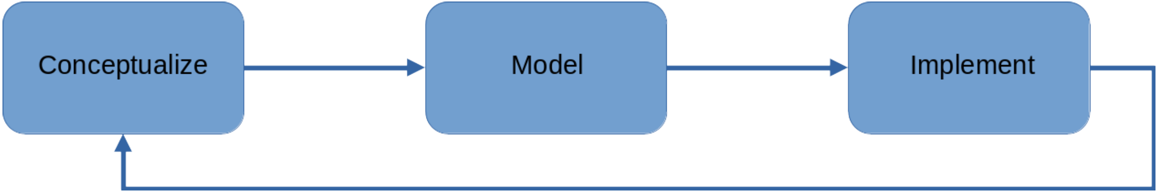
To save resources: time, manual labor, brain cells, . . .

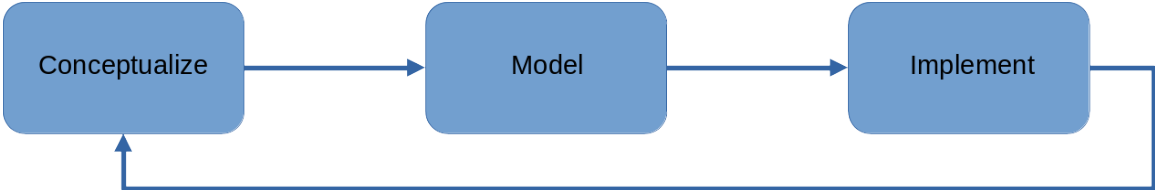
but THINK: How might a machine save resources while improving results?

Theme: Conceptualize, Model, and Implement



- Iterate
  - Human interpretation (assumption) allows ambiguity and errors to sneak in.
  - Digitalization forces rigor, exposes hidden assumptions and modeling errors.

Theme: Conceptualize, Model, and Implement



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- Example accuracy specification:
  - $\pm x$ for 10 Hz to 100 Hz
  - $\pm y$ for 0.1 kHz to 1 kHz

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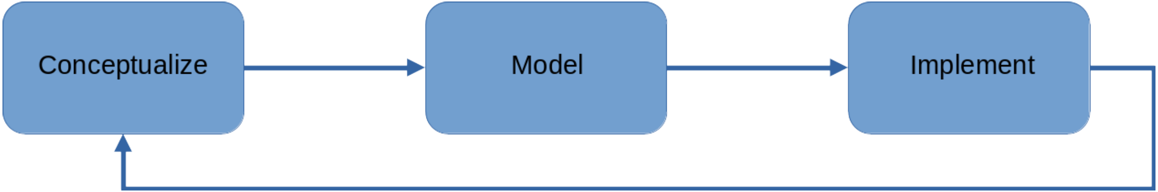

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  - Human interpretation (assumption) allows ambiguity and errors to sneak in.
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- Example accuracy specification:
  - $\pm x$ for $10\,\mathrm{Hz} \leq f < 100\,\mathrm{Hz}$
  - $\pm y$ for $0.1\,\mathrm{kHz} \leq f < 1\,\mathrm{kHz}$
  - Rethink: Model subranges to disallow overlap.
  - Rethink: Model equations for optional use.

Modeling Calibration & Measurement Capabilities

Selected detail

- M-Layer: units, scales, quantities
- Measurand taxonomy: reference metadata to identify measurands
- CMCs: abstract CMC template for concrete instantiations
- Aliases, service classifications
- Extension to instrument specifications, calibration results

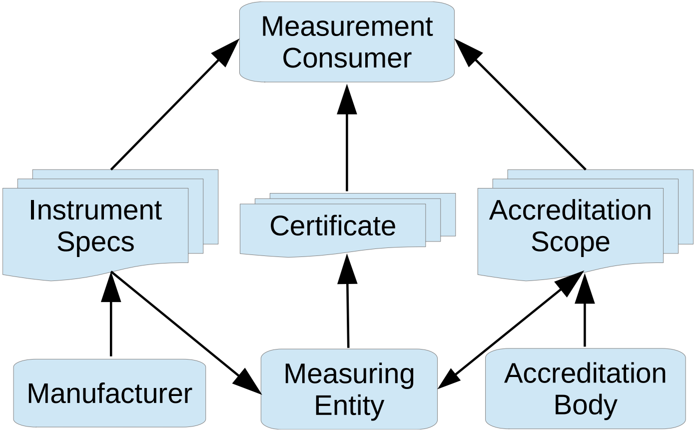
Automated Information Flow in the Measurement Economy

1. Proven modeling principles
2. Standardized metrology metadata
3. ⇒ Interoperable measurement data and services

Spec: `Source.Voltage.DC`

SoA: `Measure.Voltage.DC`

Cert: `Source.Voltage.DC`



More intentional modeling: M-Layer development

- Facilitates quantities and units handling in digital systems
- Aspects and scales reconceptualize quantity kinds and units.
- Generalizes and extends to all unit systems, scales, quantities
- PIDs for disambiguation, conversions as expressions ($\pi/180$)
- Allows consistent transformations and alternate expressions

Quantity Kind(s)	Aspect(s)
one temperature	multiple (thermodynamic temperature, Δ temperature)
one dimensionless quantity	multiple (voltage gain, reflectance, ...)
multiple log-level quantities	one aspect (e.g., log voltage gain)

Reference Metadata: Measurand Taxonomy

- Identifies the *measurand*; agnostic to technique, method, procedure
  - Example: `Source.Voltage.DC`
  - Applies to any technique from Josephson voltage arrays to handheld calibrators.
- Serves only as internal metadata; normal terminology appears in human-readable output
- `Measure.Ratio.Voltage.AC.Sinewave.Delta.Frequency` (frequency response)

Token	**Purpose**
Measure	differentiates measuring and sourcing functions
Ratio	indicates the quantity kind (dimensionless quotient)
Voltage	indicates the ratioed values' quantity
AC.Sinewave	qualifies the quantity into a specific measurand
Delta.Frequency	indicates a quantity that changes values during the measurement

- In whole, just metadata for CMCs, instrument functions, measurement results

Separate but integrated: the MII taxonomy and the M-Layer

Taxa link to the aspect ID that governs the quantity values.

Quantity Value	Aspect ID	Taxon (`Measure`...or `Source`...)
		`Length.Circumference`
		`Length.Diameter`
		`Length.Form.Flatness`
1 ft		`Length.Form.Parallelism`
12 in		`Length.Form.Perpendicularity`
0.3048 m	$\Leftrightarrow \langle \text{length} \rangle \Leftrightarrow$	`Length.Form.Roughness`
30.48 cm		`Length.Form.Roundness`
304.8 mm		`Length.Form.Sphericity`
		`Length.Form.Straightness.Axis`
		`Length.Form.Straightness.Surface`
		`Length.Radius`

Customized Mappings for Presentation

Organizations freely present terminology (aliases) and service classifications as desired:

Organization	Source.MassFlowRate.Gas	Source.MassFlowRate.Liquid
BIPM KCDB	fluid flow; gas flow	fluid flow; liquid flow
ISO-IEC 80000	mass flow rate	mass flow rate
NVLAP	[20/M05] Flow Rate; gas flow	[20/M05] Flow Rate; liquid flow
DAkkS	Mass of flowing gases	Mass of flowing liquids
DANAK	massestrøm	massestrøm

Mappings accomodate any local language or industry standard.

The Measurand Model, Taxonomy, CMCs

Model	**Ex. Template** (a defined measurand)	**Example CMC** (SoA Editor)
Taxon	`Measure.Voltage.AC`	`Measure.Voltage.AC`
Aspect	electric potential difference (AS22)	—
Definition	RMS . . . [text, link to reference point]	—
Deprecated?	false	—
	—	Uncertainty (a module of its own)
Parameters†	required: `Voltage.AC`	`Voltage.AC`, $0.1\,\mathrm{V} \leq V < 1\,\mathrm{V}^{\ddagger}$
	required: `Frequency`	`Frequency`, $100\,\mathrm{Hz} \leq f < 1\,\mathrm{kHz}^{\ddagger}$
	optional: `Waveform`	`Waveform`, Sinewave
	optional: `Impedance.Load`	`Impedance.Load`, $50\,\Omega \leq R \leq 50\,\Omega^{\ddagger}$
	optional: `Temperature.Ambient`	
	optional: `Humidity.Relative.Ambient`	

†Each parameter also has an aspect and definition (not shown).
‡Values encoded via the M-Layer in any legitimate scale or unit (not shown).

The Measurand Model Applied More Widely

Model	Ex. Instrument Function	Example Measurement Result
Taxon	`Source.Voltage.AC`	`Source.Voltage.AC`
Aspect	—	—
Definition	AC coupled ... rear input ...	AC coupled ... rear input ...
Deprecated?	—	—
	Function, Range (unique IDs)	Function, Range IDs
	Uncertainty or MPE	Uncertainty (with traceability), MPE
		Measured Value† `Measure.Voltage.AC`
Parameters	`Voltage.AC`, $0.1\,\mathrm{V} \leq V < 1\,\mathrm{V}^{\ddagger}$	`Voltage.AC`, 0.101 V
	`Frequency`, $100\,\mathrm{Hz} \leq f < 1\,\mathrm{kHz}^{\ddagger}$	`Frequency`, 100.000 01 Hz
	`Waveform`, Sinewave	`Waveform`, Sinewave
	`Impedance.Load`, $50\,\Omega \leq R \leq 50\,\Omega^{\ddagger}$	`Impedance.Load`, 49.95 Ω

†Repeat this section for nominal value, error, etc.

Acknowledgments

Many thanks go to

- NCSL International Committee members for their MII development work
- NCSL International for its MII support
- Fluke Calibration for M-Layer support
- Cal Lab Solutions for taxonomy support
- Cherine Marie-Kuster

And Thank You for your time!

Collaboration opportunities? Please bring your expertise!

Section 9

Demonstration—Metrology metadata applications

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Lunch

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Data management principles at industrial calibration labs

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Digitalization of Device Specifications

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Discussion—Accreditation and Conformance Assessment Measurement Classifications

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Q & A

Thank You To Our Members!!

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