A Guide to Standardizing Digital Calibration and Measurement Capabilities[1]

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NCSLI 141 MII and Automation Committee

Measurement-Information Infrastructure

[1] Adapted from the same-named 2021 NCSLI Workshop & Symposium presentation and paper

Section 1

Introduction

Today's Topics

1. Introduction

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2. MII Measurand Taxonomy and CMCs

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1. Introduction
2. MII Measurand Taxonomy and CMCs
3. Air-Flow Taxon and CMC Example
4. Conclusion

Learning Objectives

By participating in this learning lab and using the 2021 paper, attendees will learn to

1. state the importance of a rigorously defined CMC structure,
2. relate how to develop fully defined CMCs,
3. explain some benefits of digitally transforming metrology, and
4. spread the value of the MII taxonomy editor to colleagues.

Acronyms

Definition

MII (measurement information infrastructure)
—set of normative standards that unambiguously define data structures, taxonomies, service protocols and security for locating, communicating and sharing measurement information

- SoA—scope of accreditation
- DCC—digital calibration certificate (PTB)
- CMC—calibration and measurement capability
- MPE—maximum permissible error

Section 2

MII Measurand Taxonomy and CMCs

Paper Motivations

The paper and presentation

- Help the MII committee develop digital documents
- Provide content for the MII recommended practice
- Serve as a mini-tutorial for anyone
    - developing MII taxonomy (you?),
    - anyone writing CMCs for accreditation scopes,
    - trainers developing a full training course.

Digital Transformation

Progress	Want Music?	Want Calibration?
manual		
analog		
digitized		
digitalized		
digitally transformed		

Digital Transformation

Progress	Want Music?	Want Calibration?
manual	hire musicians	manual paper certs
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Digital Transformation

Progress	Want Music?	Want Calibration?
manual	hire musicians	manual paper certs
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Digital Transformation

Progress	Want Music?	Want Calibration?
manual	hire musicians	manual paper certs
analog	records, tapes	automated paper certs
digitized	compact disc	PDF certs (mostly)
digitalized		
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Digital Transformation

Progress	Want Music?	Want Calibration?
manual	hire musicians	manual paper certs
analog	records, tapes	automated paper certs
digitized	compact disc	PDF certs (mostly)
digitalized	tagged MP3 files	?
digitally transformed		

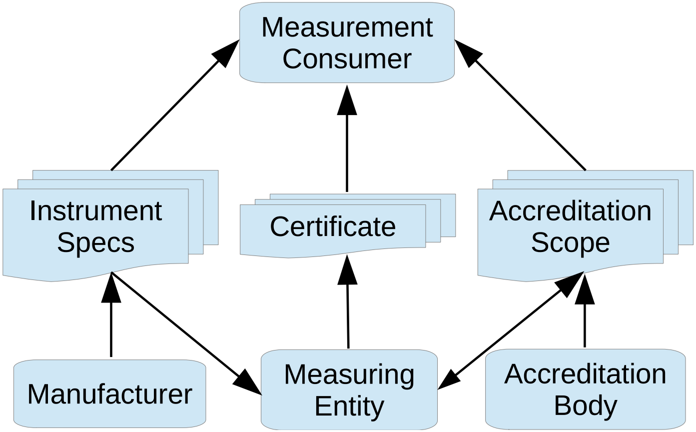
Digital Transformation

Progress	Want Music?	Want Calibration?
manual	hire musicians	manual paper certs
analog	records, tapes	automated paper certs
digitized	compact disc	PDF certs (mostly)
digitalized	tagged MP3 files	?
digitally transformed	Pandora, SiriusXM	?

Digital Transformation

Progress	Want Music?	Want Calibration?
manual	hire musicians	manual paper certs
analog	records, tapes	automated paper certs
digitized	compact disc	PDF certs (mostly)
digitalized	tagged MP3 files	MII, DCC, et al.
digitally transformed	Pandora, SiriusXM	new innovation

Partial Metrology Information Flow



Machines require metadata to process documents.

Measurement metadata = measurand descriptions = MII taxons

We want a standard measurand taxonomy.

Spec: `Source.Voltage.DC`

SoA: `Measure.Voltage.DC`

Cert: `Source.Voltage.DC`

Section 3

Air-Flow Taxon and CMC Example

Air-Flow Example

Why air flow?

- complex enough to illustrate most cases
- tackles a measurement area not yet developed

We'll develop a measurand taxon and associated CMC step-by-step.
The editor tools Mike Schwartz will present facilitate this process.

Step 0: Understand the measurement process!
Imaginary scenario:

- We have air-flow measurement experience and will learn as we go.
- We calibrate mass and volume flow meters with air and dry nitrogen.
- The MII has no existing taxon for air flow.
- The MII has defined no relevant measurement quantity.

Step 1: Name the Taxon

Step 1.1: Select the process type.

Example Taxon: `Source`

Example CMC Table

Measurand	Uncertainty	Comments
		Source for calibrating flow meters

Rule: A taxon's first token represents the process type, taking either the value `Measure` or `Source` to identify an input- or output-quantity measurement, respectively.[2]

[2] Regardless of whether the measurement process uses a direct, common source, or comparator measurement method

Step 1: Name the Taxon

Step 1.2: Separate tokens with a period.

Example Taxon: `Source.`

Example CMC Table

Measurand	**Uncertainty**	**Comments**
		Source for calibrating flow meters

Rule: Each taxon comprises a series of tokens separated by the period (.) character.

Step 1: Name the Taxon

Step 1.3: Add the measured-quantity name.

Example Taxon: `Source.air flow`

Example CMC Table

Measurand	**Uncertainty**	**Comments**
		Source for calibrating flow meters

Rule: The taxon's remaining tokens indicate the measured quantity.

Step 1: Name the Taxon

Step 1.4: Create a human-readable alias.

Example Taxon: `Source.air flow`

Example CMC Table

Measurand	Uncertainty	Comments
Air Flow		Source for calibrating flow meters

Rule: Each taxon may have aliases, such as commonly used equivalents (from *ISO-IEC 80000*, the KCDB, an AB's conventions, etc.). These aliases may appear in human-readable documents generated from the digital document as the user prefers.

Step 1: Name the Taxon

Step 1.5: Format the tokens.

Example Taxon: `Source.AirFlow`

Example CMC Table

Measurand	Uncertainty	Comments
Air Flow		Source for calibrating flow meters

Rule: Each token uses the UpperCamelCase[2] naming convention.

[2] also known as Pascal or Capitalized

Step 1: Name the Taxon

Step 1.6: Check against the MII quantity database.

Example Taxon: `Source.AirFlow??`

Example CMC Table

Measurand	Uncertainty	Comments
Air Flow		Source for calibrating flow meters

Rule: The measured quantity's first token identifies the quantity kind, which shall have an entry in the MII quantity register (M-Layer Aspect Registry).

Researching Quantity Names

Names from recognized bodies:

- KCDB: “fluid flow” (with “gas flow” or “liquid flow” and species)
- *ISO-IEC 80000*: “mass flow rate” and “volume flow rate”
- NVLAP: “[20/M05] Flow Rate”, plus “liquid flow” and “gas flow”
- DAkkS: ‘Gas flow rate”, “Volume of flowing gases”, and “Mass of flowing gases”

Neither names nor quantities consistent!

No problem–building this taxon for digital documents solves that.

Researching Quantity Names

Looking at approved SoAs from various ABs and Laboratories, we additionally find

> *"Mass Flow", "Liquid Flow", "Gas Flow", "Flow - Air", "Flow - Gas", "Flow - Liquid", "Flow - Gas (Air)", "Air/Nitrogen Flow", "Flow Rate by Volume", "Air Volume Flow", "Flow Hydraulic", "Fuel Flow", "Flow Rate by Volume for Compressible Gas", "Volumetric Flow Rate (Water)", "Liquid Flow Rate Inline", "Liquid Flow Rate Non-Intrusive", "Gas Flow - Leak", "Gas Leak", "Gas Flow Rate Into Vacuum", "mole-flow-rate", "Flow Meter Factor", "Flow Calibration Factor", "Flow Meter", "Determination of Flow Meter" (by gas or liquid species), "Electrical Output of Flow & Pressure Devices",*

and many other categorizations by flow instrumentation.

Further confusion: melt-flow index, flow velocity, air velocity, evaporation, load rate. Wow!

Researching Quantity Names

Sorting it out for the taxonomy:

- Unique quantity kinds: mass flow, volume flow, ratios, coefficients
- The MII taxonomy already defines `Ratio` and `Coefficient`.
- Mass flow covers leaks.
- Fluids include gases and liquids but their measurement processes differ.
- A species-type property would identify the fluid.
- Both inline and non-intrusive Measure processes exist, though the Source process seems the same.

Solution: Propose adding `MassFlowRate` and `VolumeFlowRate` to the MII quantity-kind list.

Step: Organize a Hierarchical Taxonomy Tree

- Source.MassFlowRate.Gas
- Measure.MassFlowRate.Gas.Inline
- Measure.MassFlowRate.Gas.NonIntrusive
- ...MassFlowRate.Liquid...
- Source.VolumeFlowRate.Gas
- Measure.VolumeFlowRate.Gas.Inline
- Measure.VolumeFlowRate.Gas.NonIntrusive
- ...VolumeFlowRate.Liquid...
- Source.Ratio.MassFlowRate.Gas.MeterFactor
- Source.Coefficient.Voltage.MassFlowRate.DC.Gas

Only the whole taxon has machine meaning; individual tokens (except Measure and Source) only facilitate development.

Step 1: Name the Taxon

Step 1.6: Check against the MII quantity database.

Example Taxon: `Source.MassFlowRate`

Example CMC Table

Measurand	Uncertainty	Comments
Mass flow rate		Source for calibrating flow meters

Rule: The measured quantity's first token identifies the quantity kind, which shall have an entry in the MII quantity register.

Step 1: Name the Taxon

Step 1.7: Completely qualify the measurand.

Example Taxon: `Source.MassFlowRate.Gas.AmbientAir`

Example CMC Table

Measurand	**Uncertainty**	**Comments**
Mass flow rate Gas: ambient air, dry nitrogen		Source for calibrating inline or non-intrusive flow meters

Rule: Any further tokens after the quantity-kind token hierarchically qualify the quantity, proceeding from more general toward more specific quantity descriptors.

Step 1: Name the Taxon

Step 1.8: Omit qualifiers that do not change the measurement process.

Example Taxon: `Source.MassFlowRate.Gas`

Example CMC Table

Measurand	Uncertainty	Comments
Mass flow rate Gas: ambient air, dry nitrogen		Source for calibrating inline or non-intrusive flow meters

Rule: Parameters substitute for additional tokens to distinguish details within the same measurement process.

`Source.Temperature.Simulated.Thermocouple` (types by parameter)
`Source.Temperature.Simulated.PRT` (resistance instead of voltage)

Step 2: Define the Measurand

A clear human-readable definition helps (M-Layer!)

- disambiguate one measurand from another,
- select the correct measurand from a list,
- determine whether the measurand of interest appears in the taxonomy or requires a new entry or differentiation.

Find a suitable definition in a textbook, standard, or other source.

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Find a suitable definition in a textbook, standard, or other source.
In our case, we find a succinct mathematical definition in *ISO-IEC 80000*: $q_m = dm/dt$
We might then expound upon that to give more explanation:

> *This process sources a reference mass flow rate of gas for calibrating gas flow meters. The instantaneous mass flow rate q_m equals dm/dt, sometimes estimated as $\Delta m/\Delta t$ using the total mass Δm flowing through a defined space in time Δt.*

Lies, Damned Lies, and Statistics

If a probability equals p only under conditions (x, y, z), then we abuse the facts to quote the probability without stating the conditions.

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Similarly, we devalue calibration without fully knowing and stating the measurement conditions, the measurand's state.
(Calibrate as used, use as calibrated! How? Define the state!)

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Similarly, we devalue calibration without fully knowing and stating the measurement conditions, the measurand's state.
(Calibrate as used, use as calibrated! How? Define the state!)

- Specifying the measurand's full state restricts its *definitional* uncertainty.
- Unrecognized definitional uncertainty may swamp other uncertainty components.
- At worst, it will exceed the instrument MPE specification, essentially making the calibration worthless.

Lies, Damned Lies, and Statistics

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(Calibrate as used, use as calibrated! How? Define the state!)

Define the measurand's state via "parameters" included as metadata in instrument specifications, calibration certificates and SoAs.

- Influence quantity values (e.g., frequency in AC voltage)
- Input quantity values (e.g., temperature for length correction)
- Property values (e.g., thermocouple type)
- Instrument operating conditions (might challenge some labs)

Step 3: Identify the Measurand's Parameters

Step 3.1: Research calibration processes for the measurand.

- Mass flow rate
- Gas Type
- Gas Temperature
- Gas Pressure
- Gas Relative Humidity
- Gas Compressibility
- Reference Temperature
- Reference Pressure
- Reference Relative Humidity
- Reference Compressibility
- Ambient Temperature
- Ambient Pressure
- Ambient Relative Humidity
- Outlet Pressure
- Reynolds Number
- Gas Velocity

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Not all parameters matter for a given laboratory or customer—uncertainty level and instrument type.

Step 3: Identify the Measurand's Parameters

Step 3.2: Classify parameters as required or optional (default-valued).

- Mass flow rate
- Gas Type
- Gas Temperature
- Gas Pressure
- Gas Relative Humidity
- Gas Compressibility
- Reference Temperature
- Reference Pressure
- Reference Relative Humidity
- Reference Compressibility
- Ambient Temperature
- Ambient Pressure
- Ambient Relative Humidity
- Outlet Pressure
- Reynolds Number
- Gas Velocity

Not all parameters matter for a given laboratory or customer—uncertainty level and instrument type.

Step 3: Identify the Measurand's Parameters

Step 3.2: Classify parameters as required or optional (default-valued).

- Mass flow rate (R)
- Gas Type
- Gas Temperature
- Gas Pressure
- Gas Relative Humidity
- Gas Compressibility
- Reference Temperature
- Reference Pressure
- Reference Relative Humidity
- Reference Compressibility
- Ambient Temperature
- Ambient Pressure
- Ambient Relative Humidity
- Outlet Pressure
- Reynolds Number
- Gas Velocity

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Step 3: Identify the Measurand's Parameters

Step 3.2: Classify parameters as required or optional (default-valued).

- Mass flow rate (R)
- Gas Type (O)
- Gas Temperature (O)
- Gas Pressure (O)
- Gas Relative Humidity (O)
- Gas Compressibility (O)
- Reference Temperature (O)
- Reference Pressure (O)
- Reference Relative Humidity (O)
- Reference Compressibility (O)
- Ambient Temperature (O)
- Ambient Pressure (O)
- Ambient Relative Humidity (O)
- Outlet Pressure (O)
- Reynolds Number (O)
- Gas Velocity (O)

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- Reference Compressibility (O)
- Ambient Temperature (O)
- Ambient Pressure (O)
- Ambient Relative Humidity (O)
- Outlet Pressure (O)
- Reynolds Number (O)
- Gas Velocity (O)

Laboratories may change the required-optional assignment and omit parameters altogether in their CMCs.

Example Human-Readable MII Air-Flow Taxon

Source.MassFlowRate.Gas

This process sources a reference mass flow rate of gas for calibrating gas flow meters. The instantaneous mass flow rate q_m equals dm/dt, sometimes estimated as $\Delta m/\Delta t$ using the total mass Δm flowing through a defined space in time Δt.

- **Required Parameters**
  - Mass flow rate
- **Optional Parameters**
  - Gas Type
  - Gas Temperature
  - Gas Pressure
  - Gas Relative Humidity
  - Gas Compressibility
  - Reference Temperature
  - Reference Pressure
  - Reference Relative Humidity
  - Reference Compressibility
  - Ambient Temperature
  - Ambient Pressure
  - Ambient Relative Humidity
  - Outlet Pressure
  - Reynolds Number
  - Gas Velocity

Example Human-Readable CMC

Measurand	Uncertainty	Comments
Mass flow rate, 1 slpm to 1000 slpm Gas: ambient air, dry nitrogen Gas Temp. (inlet): 23 °C Gas Pressure (inlet): 800 kPa 100 kPa to 1000 kPa Gas Relative Humidity: 45 % Ref. Temperature: 20 °C Ref. Pressure: 101.325 kPa Ref. Relative Humidity: 36 % Ref. Compressibility: 0.9997 Ambient Temperature: 23 °C Ambient Pressure: 800 kPa . . .	±0.3 % of reference value*	Source for calibrating inline or non-intrusive flow meters

Section 4

Conclusion

Digitize your CMCs!

1. Metrology's digital transformation has begun; coming our way soon!
2. The MII initiative paves a way to digitize your CMCs.
3. Digital CMCs will draw new business and reduce costs.
4. The taxonomy editor and SoA editors will make this easy.
5. We will reuse the taxonomy in digital instrument specifications and calibration certificates.
6. We'd like to collaborate on your CMCs.
7. SoA content and formatting remains under the laboratory's and AB's control.

"If in the last few years you haven't discarded a major opinion or acquired a new one, check your pulse. You may [have died]."
—from Frank Gelett Burgess

Acknowledgments

Please see the paper for further taxon-writing details.
See also Demystifying Accreditation Scopes" (hwade@HeatherWadeGroup.com).

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- Cherine-Marie Kuster

And Thank You for your time!

Collaboration opportunities? Please bring your expertise!

Questions?