engineering laboratory

On-machine measurement (OMM) use cases to enhance digital thread standards

John Horst

Digital Thread for Smart Manufacturing Project

Intelligent Systems Division

NIST

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Road map

- Motivation
- OMM use cases for semantic information
- Next steps

Motivation:
Need for integration of QIF and MTConnect

- DMSC and MTConnect joint work on OMM
  - O3 DMDII project
  - ‘Concise Measured Points’
- QIF and MTConnect
  - MTConnect: streaming, real-time
  - QIF: file-based, non-real time

Motivation:
Need for semantic-rich OMM information

- Benefits
  - Track down root causes
  - Satisfy Industrial IoT requirements

OMM use cases:

Semantic information from OMM use cases:

- Use cases and activities for measurement and machining
- Exposed semantic information for I/O
- 27 OMM use cases

OMM use cases:

OMM, IPM,
PPM defined

Images courtesy of Renishaw plc and Faro Technologies, Inc.

Taxonomy for OMM use cases

Define common terms, that are non-overlapping, as well as precise

- Where: ***On-machine measurement***
- When: ***Pre-process and In-process measurement***
- Why: ***Measurement, Calibration, and Verification***
  - Measurement: To generate a number with units of measure which corresponds to a characteristic on a part, such as dimensional units (*e.g.*, length, radius, volume)
  - Calibration: Measuring and adjusting something, *e.g.*, machine tool axes, probe, or cutting tool, so that it can be used to perform a more accurate measurement
  - Verification: Checking if features on a part are within specified tolerances before the machining or assembly process is complete

Six unique OMM use case types

- On-machine, Pre-process, Measurement
- On-machine, Pre-process, Calibration
- On-machine, Pre-process, Verification
- On-machine, In-process, Measurement
- On-machine, In-process, Calibration
- On-machine, In-process, Verification

[On-machine, Pre-process] use cases

- Calibration use cases
  - Select and calibrate cutting tools
  - Calibrate machine tool prior to operation on stock (or part) for machine tool alignment
  - Select and calibrate probe on the MT's spindle
  - Calibrate probe using the "reference comparison" or "artifact comparison" method
- Verification use cases
  - Simulate the on-machine measurement program
  - Verify that the NC code is appropriate for stock or part
- Measurement use cases
  - Measure jig or fixture for MT alignment
  - Measure and align stock via software to allow accurate machining
  - Measure raw stock
  - Measure the need for cooling or cleaning operations
  - Generate machine tool offsets using a reference part, previously measured by an environmentally controlled CMM, to later measure in-situ with a comparator gage
  - Determine the features to be measured (on-machine) and measurement frequency
  - Select measurement strategy
  - Assess needs for probe setting, tool setting, MT calibration, part cleaning or cooling

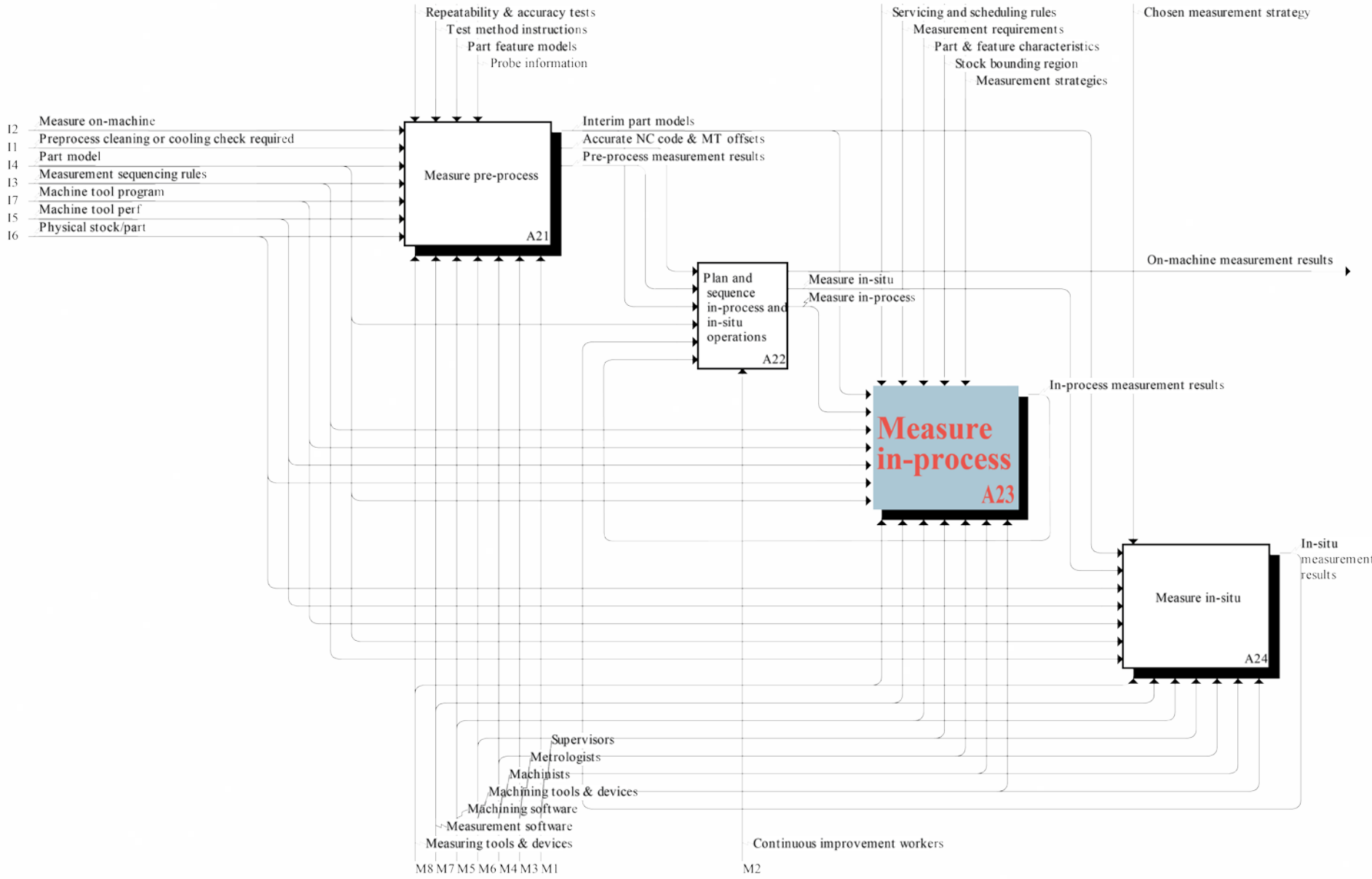
[On-machine, In-process] use cases

- Calibration use cases
  - Calibrate machine tool
  - Perform calibration, datuming, or self-datuming on probe, spindle, rotary table, or pivot points
- Verification use cases
  - Validate on-machine probe against CMM probes at “first part”
  - Detect absent, broken, or chipped tool in real-time
- Measurement use cases
  - Measure features with probe on the machine tool spindle
  - Perform tool setting or tool self-datuming
  - Assess needs for probe setting, tool setting, MT calibration, part cleaning or cooling
  - Measure tool for wear
  - Add if…then logic in the machining program to perform alternative measurements
  - Measure one critical feature for each cutting tool approach
  - Remove chips and liquid from the work piece, and stabilize temperature variance
  - Create and execute measurement software in-line with G-code
  - Alert machine tool operator of error

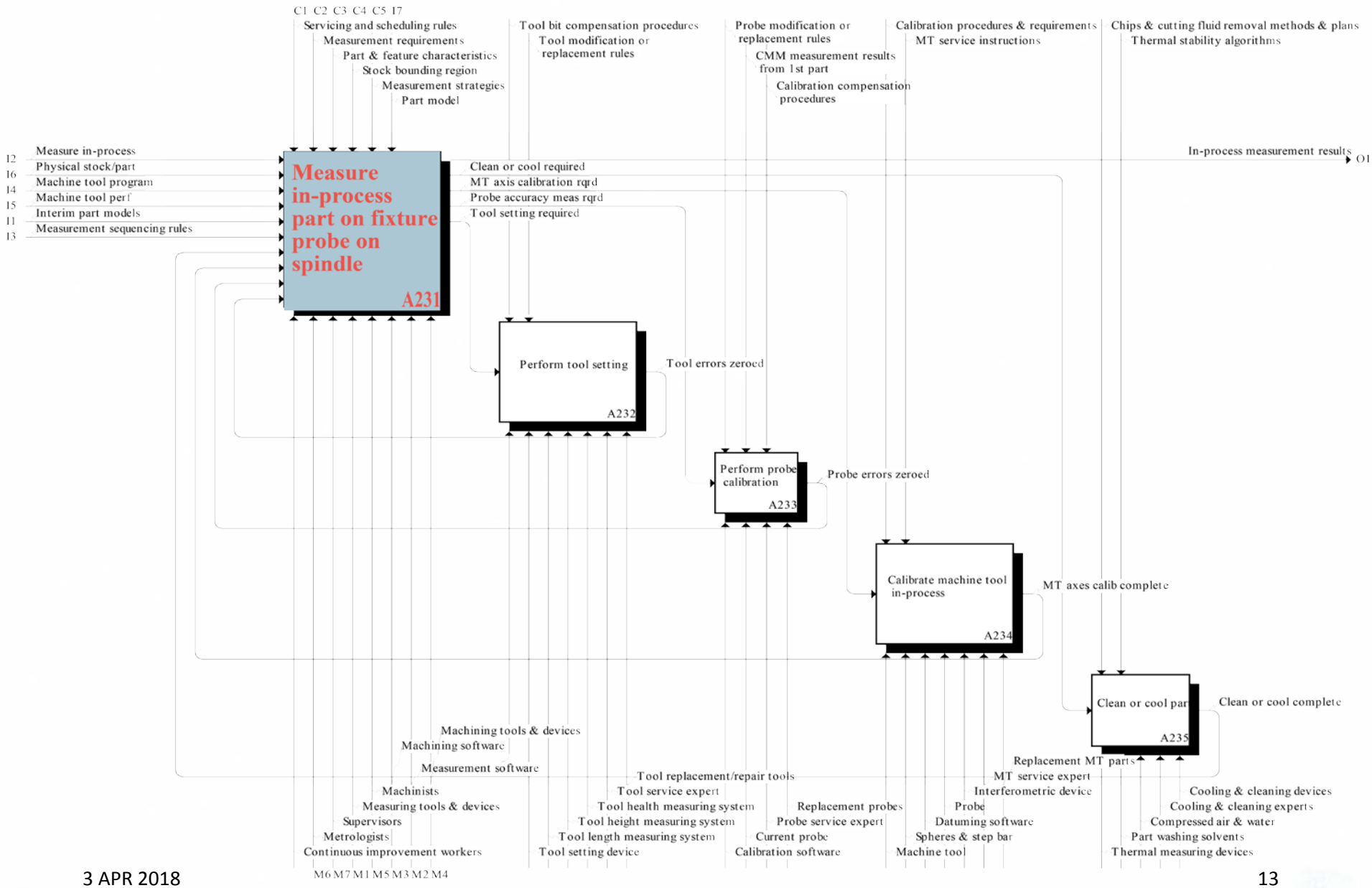
[On-machine, In-process] use cases

- Calibration use cases
  - Calibrate machine tool
  - Perform calibration, datuming, or self-datuming on probe, spindle, rotary table, or pivot points
- Verification use cases
  - Validate on-machine probe against CMM probes at “first part”
  - Detect absent, broken, or chipped tool in real-time
- Measurement use cases
  - Measure features with probe on the machine tool spindle
  - Perform tool setting or tool self-datuming
  - Assess needs for probe setting, tool setting, MT calibration, part cleaning or cooling
  - Measure tool for wear
  - Add if…then logic in the machining program to perform alternative measurements
  - Measure one critical feature for each cutting tool approach
  - Remove chips and liquid from the work piece, and stabilize temperature variance
  - Create and execute measurement software in-line with G-code
  - Alert machine tool operator of error

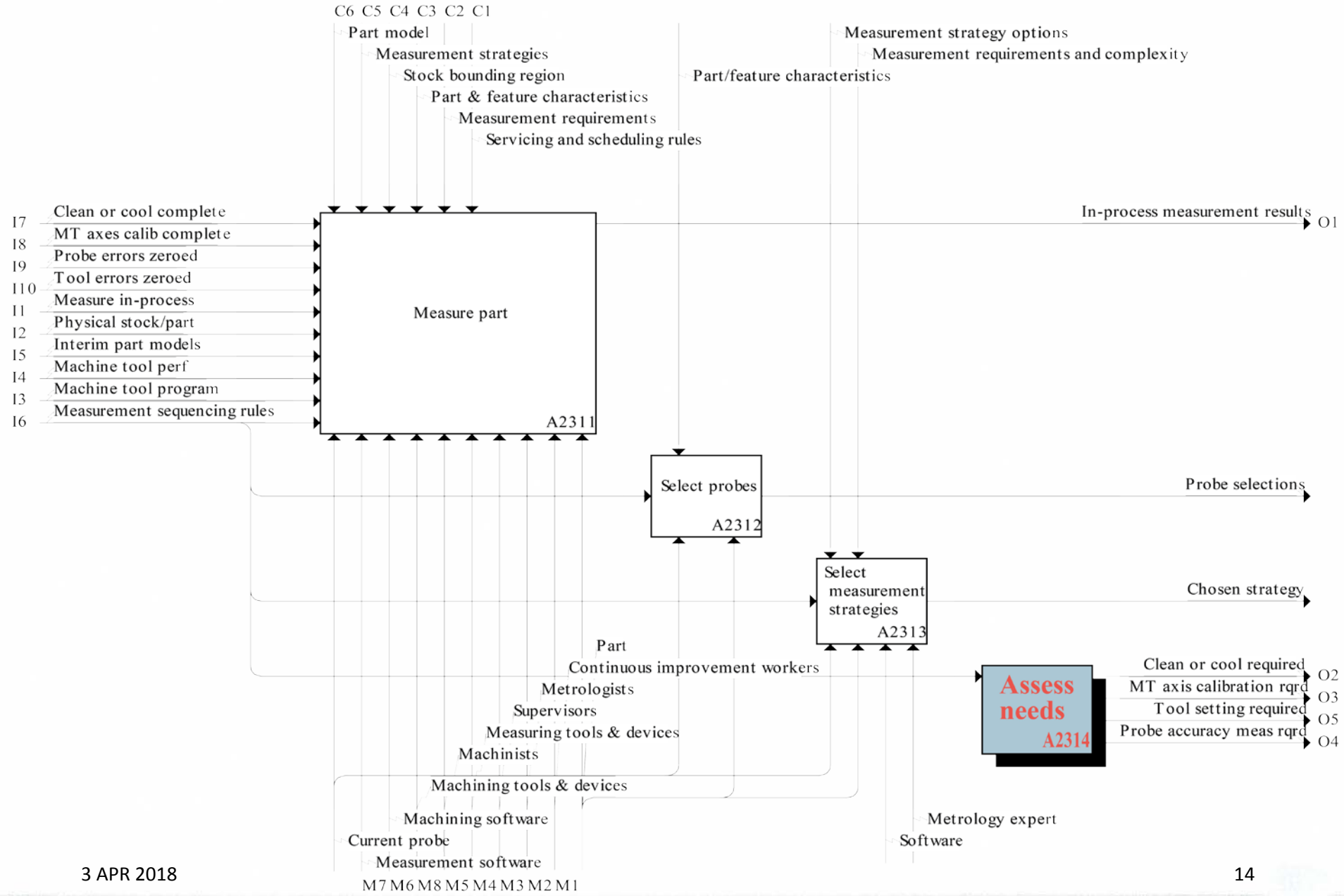
Measure on-machine



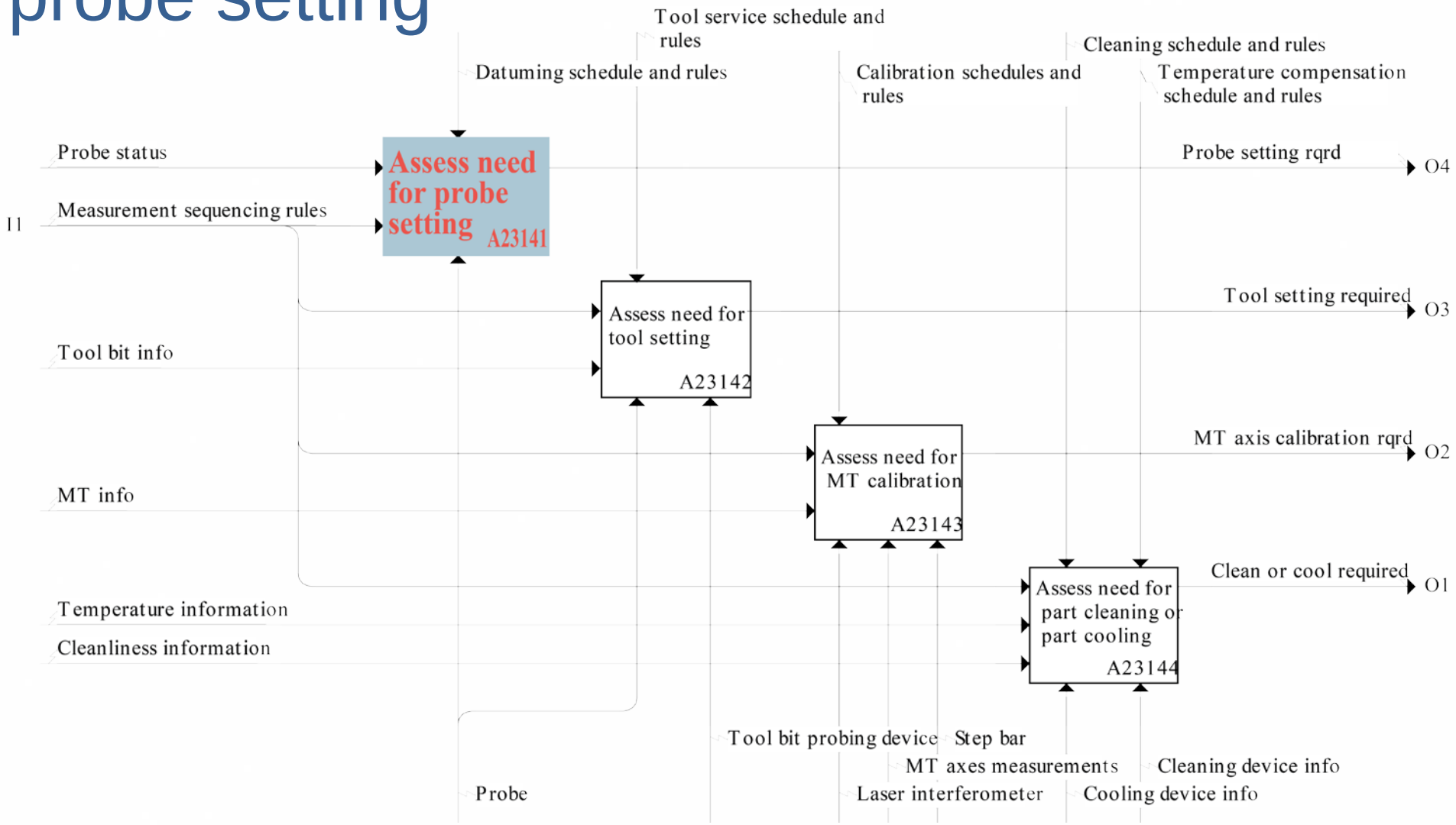
On-machine, In-process, Probe on spindle



On-machine, In-process, Assess needs



On-machine, In-process, Assess need for probe setting



OMM output information (by use case type)

- Calibration use case output info
  - Machine tool offsets from tool, fixture, stock, and s/w fixturing measurements
  - Modified G-code for calibration
  - Probe type, triggering error, and offsets
- Verification use case output info
  - Verified measurement G-code
  - Interim part models
  - Cleaning & cooling system directives
- Measurement use case output info
  - Pre-process and in-process feature measurements
  - Stock, jig, fixture, & tool measurements
  - Date, time, & location of measurement operations
  - Machine tool offsets from comparator gage on ref part
  - Machine tool offsets from probe triggering error
  - Features to be measured
  - Part & feature measurement frequencies
  - Calibration results for machine tool axes, probes, artifacts, spindle, rotary table, pivot points, gages, tool and probe setting devices, calibration spheres, etc.
  - Machine tool axes fixed or modified
  - Tool presence/absence
  - Tool broken or chipped
  - Operator error detected and type of error
  - Probe selections
  - Chosen measurement strategies
  - Probe triggering error
  - G-code accuracy
  - Time since calibration for probe or tool
  - Tool, fixture, stock, fixture, probe, cleaning, cooling, machine tool axes, swarf, and cutting fluid measurements
  - Preprocess cleaning or cooling check required
  - Date, time, & location of measurement operations
  - Measurement sequencing rules
  - Failure mode and product approval output
  - Name, model, serial #, type, date, and location for measurement related elements such as parts, features, measuring tools and devices, measurement software, machining software, machine tools & devices, machinist names and info, metrologist names and info, supervisor names and info, continuous improvement workers names and info

OMM input information for “Measure feature with probe on a CNC machine tool spindle” use case

- Machine tool characteristics
  - Machine type, *e.g.*, 6-axis, 5-axis, 4-axis, 3-axis
  - Machine tool performance values [probe speed, probe accuracy]
- Interim part model number [i = 1...n], includes the final model
- Subset of all features required to measure on the i^{th} interim part [i = 1...n] (see feature types listed below)
- Finished part model
- Subset of all features required to measure on the finished part (see feature types listed below)
- Measurement strategies
  - Probe speed of approach for measurement [maximum speed, safe speed]
  - Program with G-code measurement modules, or use external software
- Stock bounding region
- Part and feature characteristics
- Measurement requirements
- Measurement strategies
- Servicing and scheduling rules
- Cleaning operations status
  - Probe tip clean, y/n
  - Part surface clean, y/n
- Cooling operations status
- MT axes calibration status
- Tool errors status
- Measure in-process command
- Physical stock/part name and number
- Machine tool program format, *e.g.*, G-code program, proprietary, STEPNC
- Feature measurement sequencing rules
- Feature measurement sequence
- Probe characteristics
  - Probe type [touch [kinematic resistive or strain gage], non-contact optical, non-contact laser, 2D, or 3D]
  - Length of shank plus ball
  - Ball type *e.g.*, spherical, elliptical
  - Ball radius/width
  - Calibration status [probe axis offsets [Δx, Δy, Δz], time since last calibration]
  - Probe approach speeds for measurement [maximum, safe]
  - Probe accuracy at [maximum, average, slow] approach speeds

- Part feature information types
  - Boss: variable dimensions, commonly [radius, height]
  - Chamfer: variable dimensions, commonly [width, angle]
  - Cone: bottom center [x_0, y_0, z_0] normal vector = [a, b, c], [height, base radius]
  - Cylinder: bottom center [x_0, y_0, z_0] normal vector = [a, b, c], [height, radius]
  - Fillet: variable dimensions, commonly [radius, angle]
  - Counterbore hole: bottom center [x_0, y_0, z_0] normal vector = [a, b, c], [radius, depth]
  - Countersink hole: bottom center [x_0, y_0, z_0] normal vector = [a, b, c], [top radius, bottom radius, depth]
  - Simple hole: bottom center [x_0, y_0, z_0] normal vector = [a, b, c], [radius, depth]
  - Intersect circle: the intersection between a cylinder and a plane where the plane is perpendicular to the cylinder axis, [cylinder radius, plane height]
  - Intersect line: the line formed for the intersection of two planes, [slope, y-intercept]
  - Intersect plane: the plane for at the intersection of a cylinder and cone, center = [x_0, y_0, z_0] normal vector = [a, b, c]
  - Intersect point: A point derived at the intersection of a plane and the axis of a cylindrical or conical face [x, y, z]
  - Notch: Two parallel planes bounded by a plane perpendicular or a cylinder tangent to the side planes, with or without a planar blind end condition
  - Plane: position = [x, y, z], normal vector = [a, b, c]
  - Pocket: An internal extruded type closed profile, with or without a planar blind end condition
  - Slot: Two parallel planes bounded by two planes perpendicular or two cylinders tangent to the side planes, with or without a planar blind end condition
  - Surface: A non-prismatic face
  - Width: Two parallel planes with opposing normal vectors
  - Sphere: An internal or external spherical face. Radius = r, center point [x, y, z], type = internal or external
  - Free surface: Non-Uniform Rational B-spline (NURB) surface model parameters

Summary of OMM use cases

- 27 OMM use cases
  - Expose OMM information in/out
- OMM information
  - Provides content for standards
  - Provides links to the Industrial IoT

Next steps

- Propose new OMM information structures for QIF
  - *e.g.*, {contact point, surface normal, feature type, part number, …, pre-process, on-machine, ..., fixture measurement, …, machine #, bldg. #, shift #, time, …}
- Integrate OMM information into MTConnect
- Implement and test
- Report results, publish, discuss, recommend

Questions?

NIST

MTConnect®

QIF