RULE MODEL OF FEATURE INSPECTION AND RESOURCE SELECTION FOR DIMENSIONAL MEASUREMENT PLANNING

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Outline

- Background
- Quality Information Framework
- Activity Model
- Rule Model
- Sample Instances
- Conclusion

Background

Dimensional inspection planning is "one of outstanding activities in manufacturing process automation."

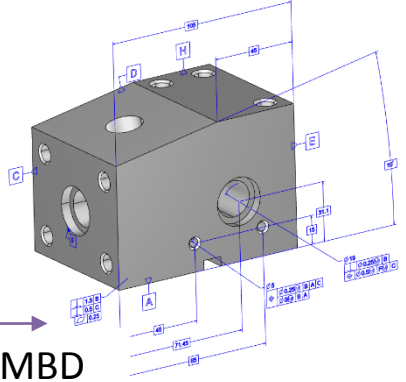
- Design features are sophisticated and geometries are complicated.
- Surface roughness and reflectivity affect measurements.

AND

- Measurement requirements are high.
  - Low measurement uncertainty.
  - Sensor-accessible to diverse features.
  - Short measurement and lead times.
  - Stringent requirements on working environment.

Martinez-Pellitero, S. et al. "Categorization of Inspection Elements in Coordinates Measurement for KBE Implementation," Procedia Engineering 132 (2015) 1037 – 1044

Design



Customer Needs → Conceptual Design → Functional Model /Concept design → Detailed Design → MBD

- Functional design
- Embodiment design
- Concept and functions

- Geometric design
- GD&T association
- Notes

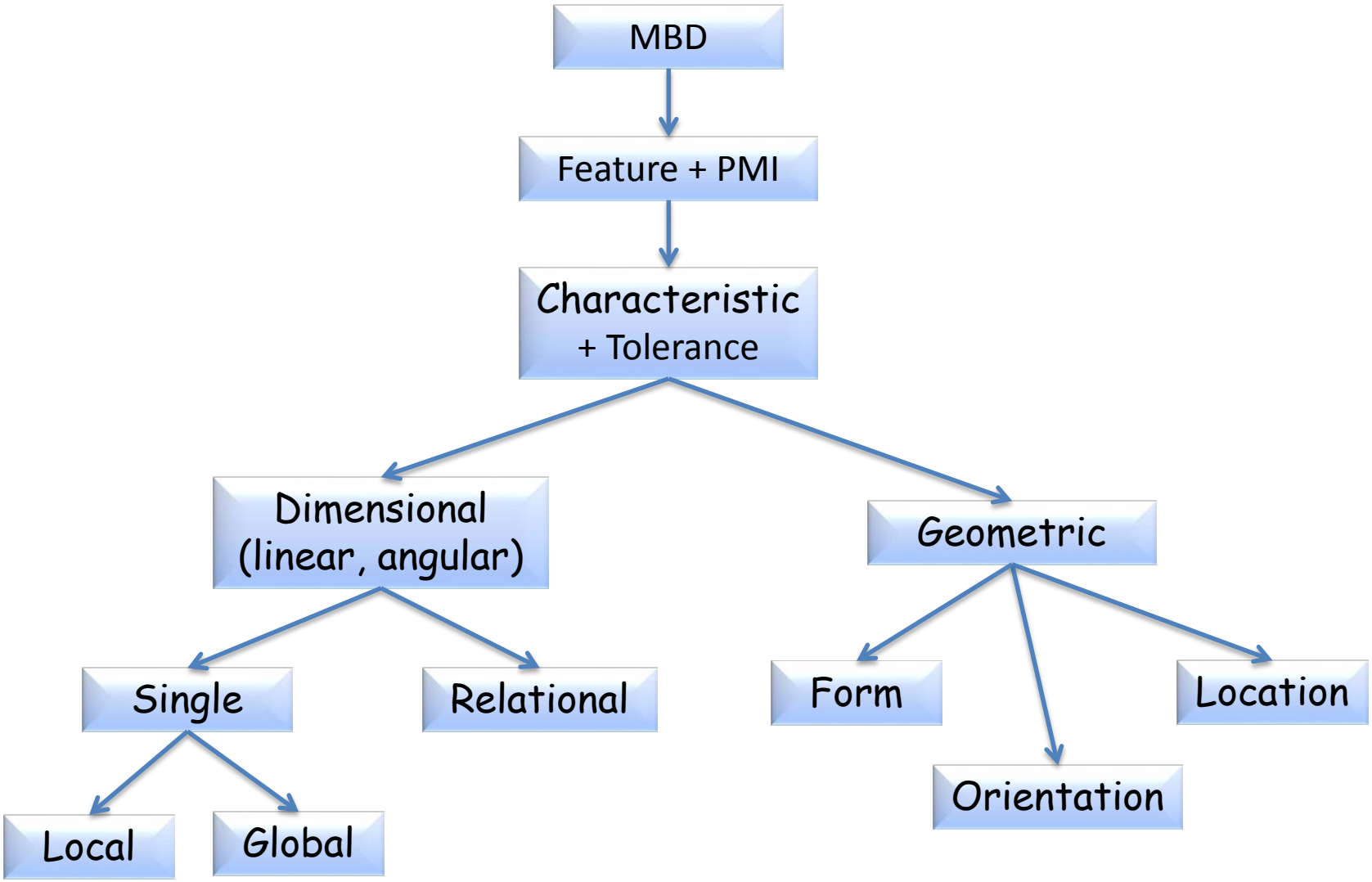
Measurement

DME, Rules → Measurement Planning

MBD → Measurement Planning → Measurement Plan → Measurement → Measured Data → Analysis & Reporting → Report

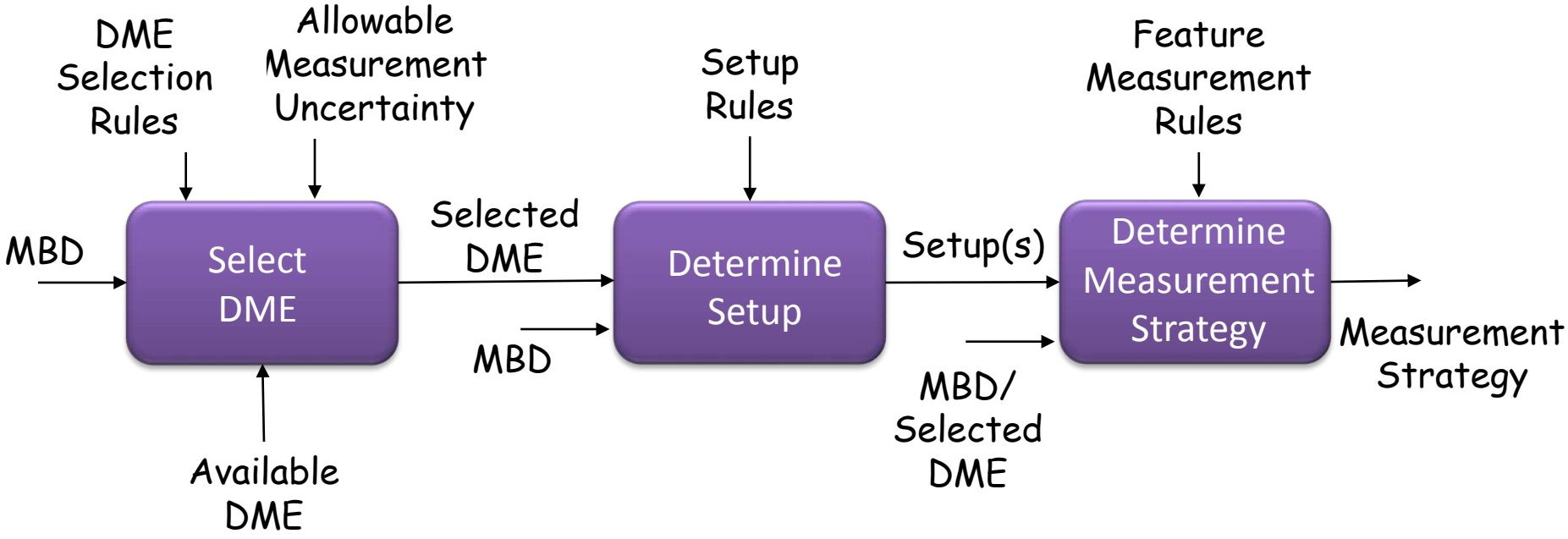
- Resource selection
- Setup
- Measurement strategy
- Tasks

Design Characteristic



Reference: ISO 17450-1 Geometrical product specifications (GPS) - General concepts - Part 1: Model for geometrical specification and verification

Measurement Planning



DME: Dimensional Measurement Equipment

References:

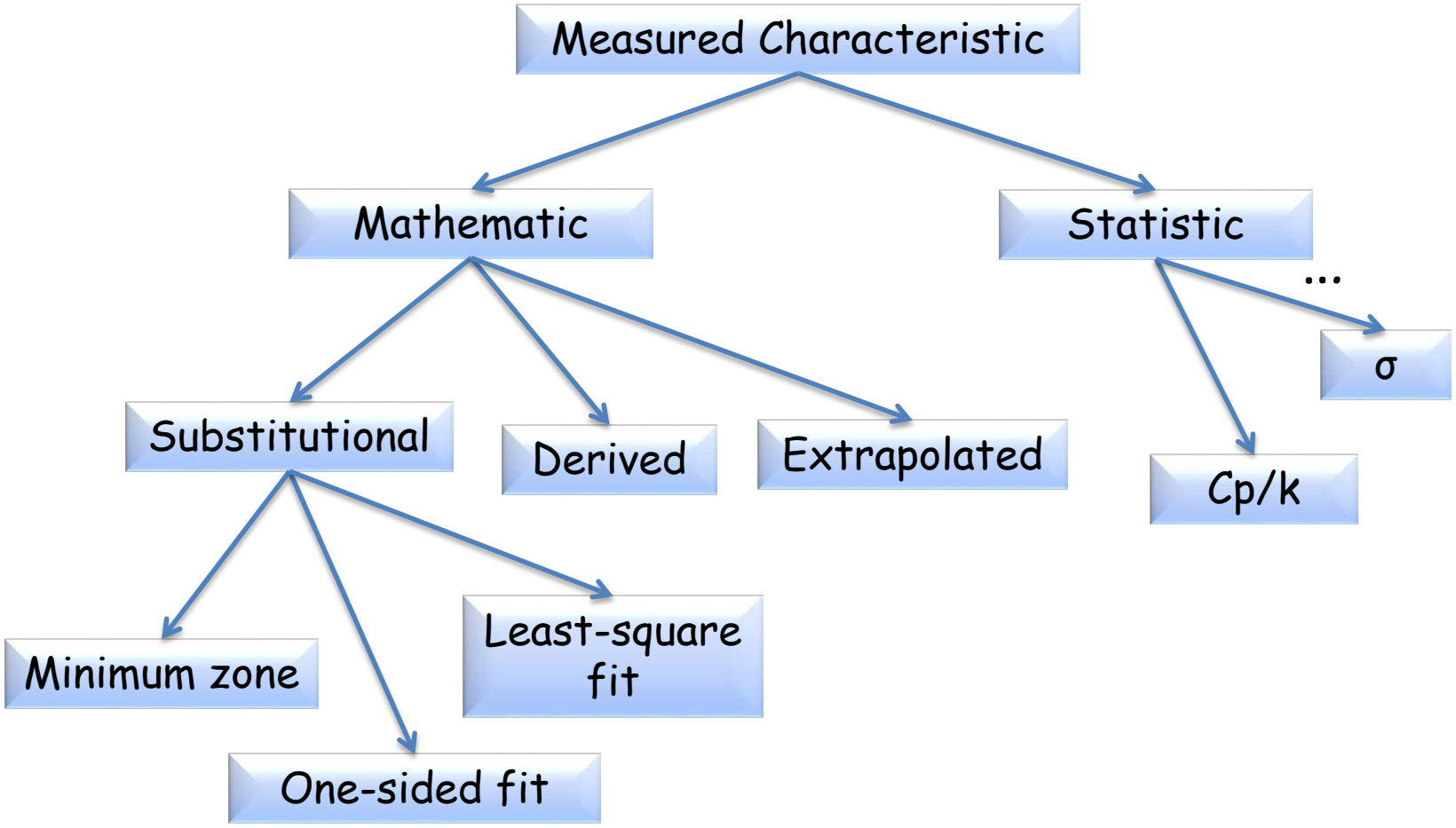
ISO 15530-3 Geometrical product specifications (GPS) -Coordinate measuring machines (CMM): Technique for determining the uncertainty of measurement - Part 3: Use of calibrated workpieces or measurement standards

ISO 13385-1 Geometrical product specifications (GPS) -Dimensional measuring equipment – Part 1: Calipers; Design and metrological characteristics

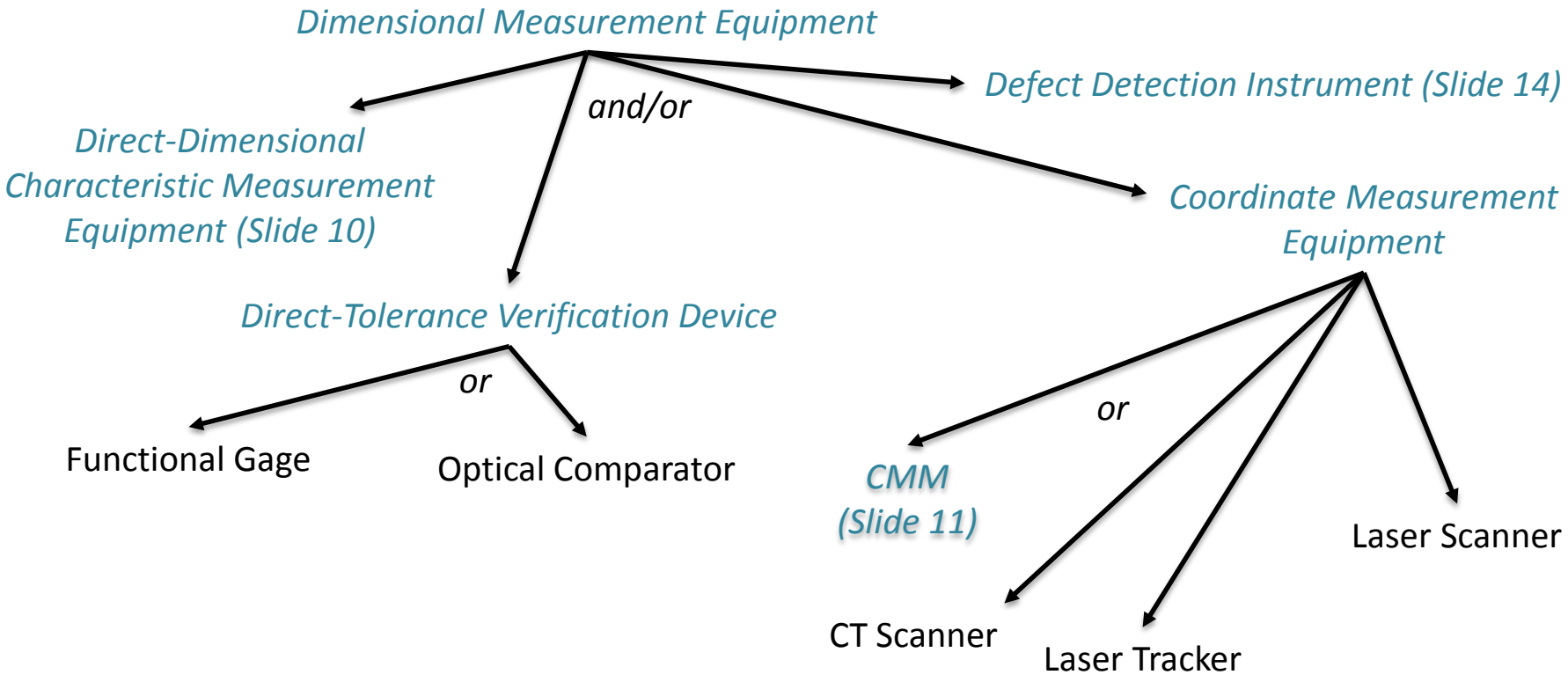
ISO 14660-1 Geometrical Product Specifications (GPS) —Geometrical features —Part 1: General terms and definitions

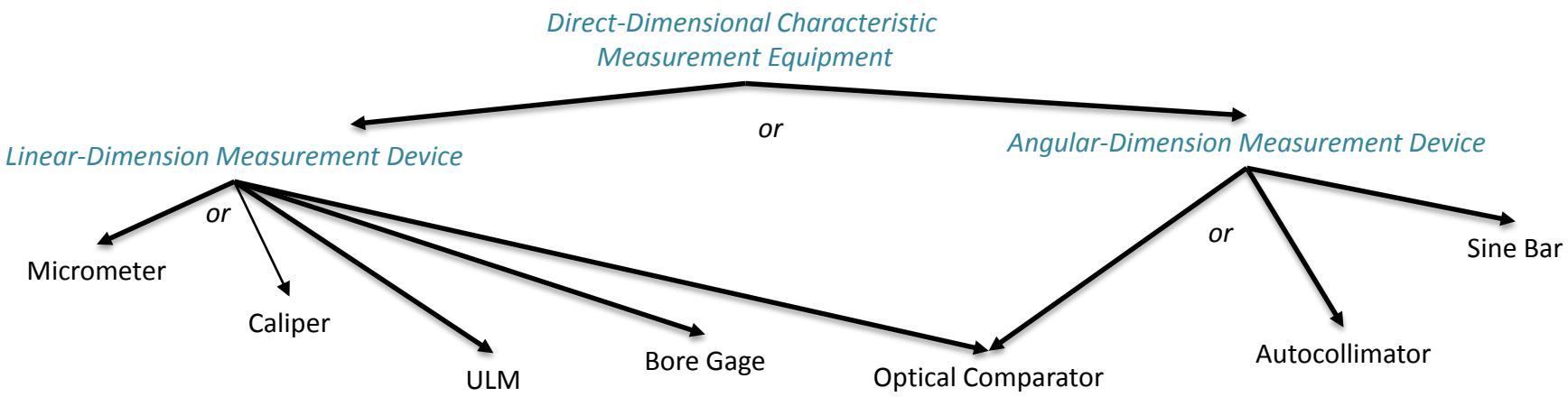
ISO 25378 Geometrical product specifications (GPS) - Characteristics and conditions - Definitions

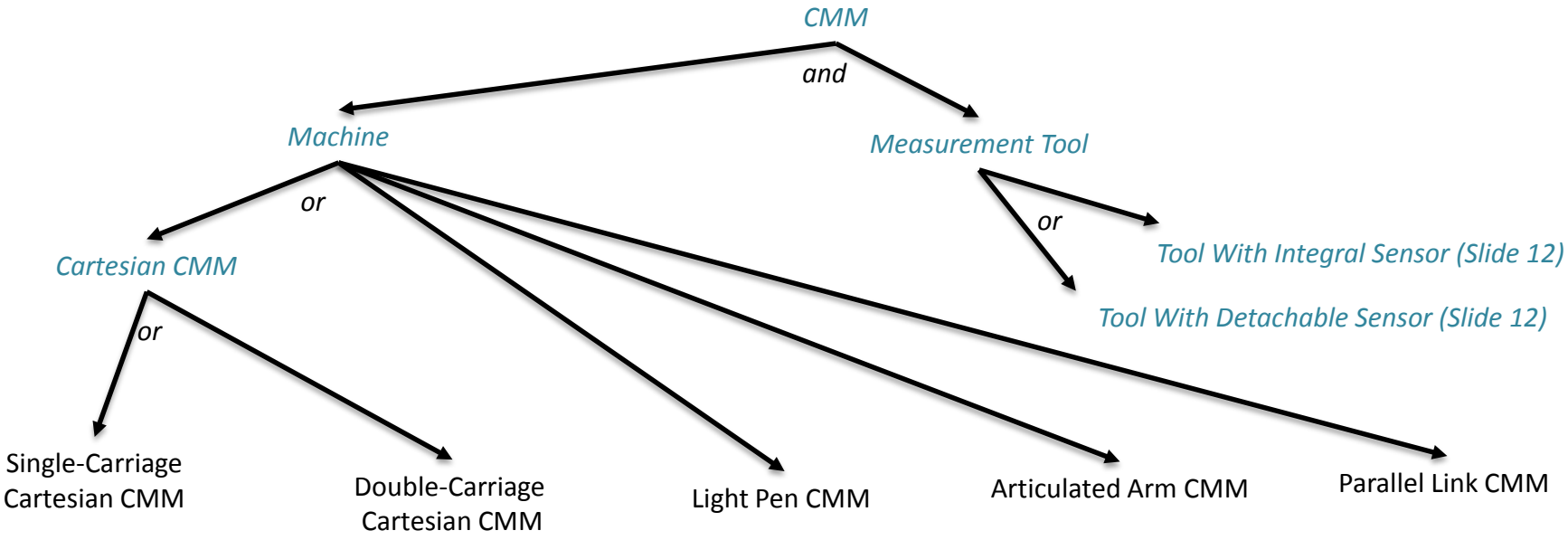
Measured Characteristic

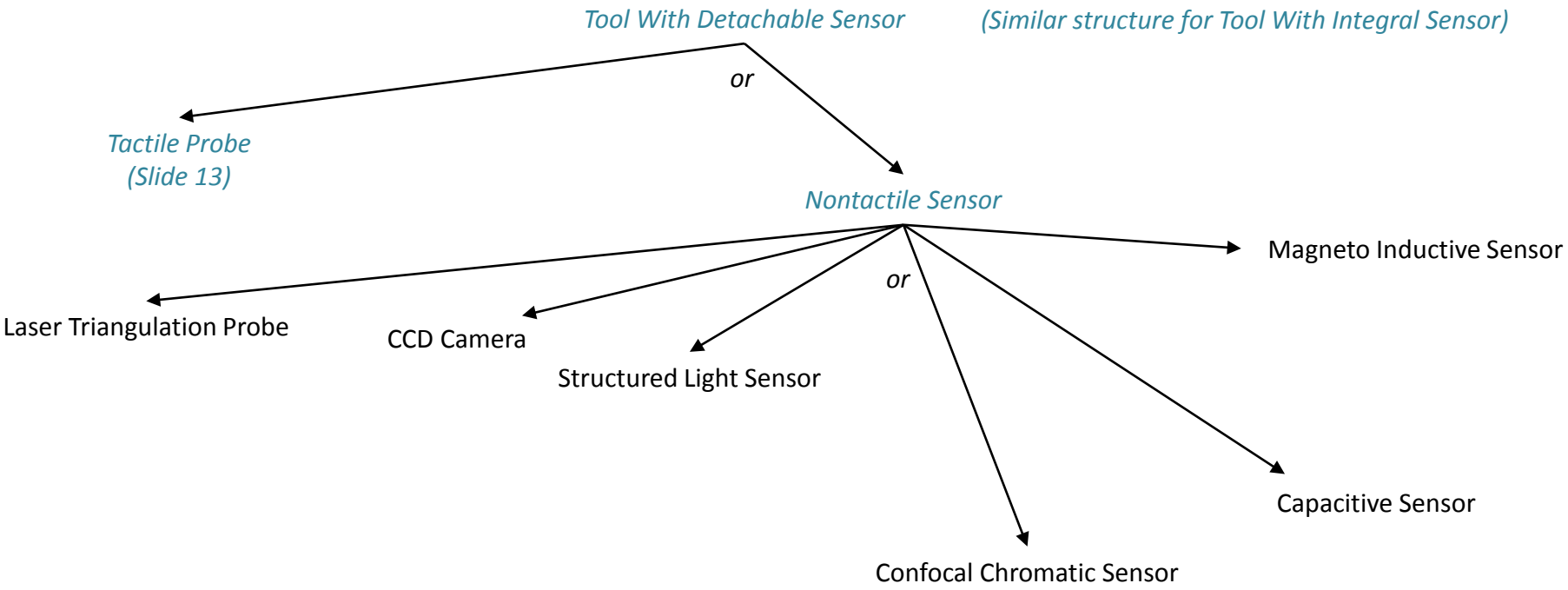


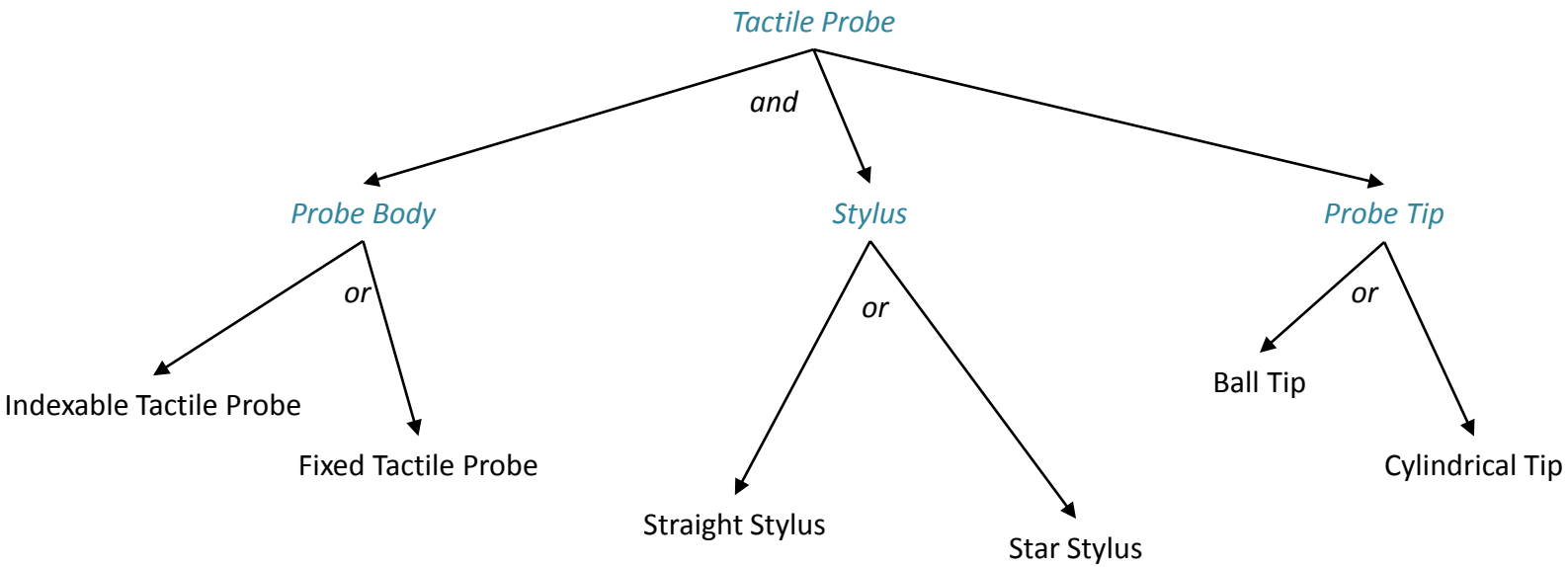
Furthermore, **Dimensional measurement equipment** has become very sophisticated and versatile.




Direct-Dimensional Characteristic
Measurement Equipment
or
Linear-Dimension Measurement Device
Angular-Dimension Measurement Device
or
Micrometer
Caliper
ULM
Bore Gage
Optical Comparator
or
Sine Bar
Autocollimator


CMM
and
Machine
Measurement Tool
or
or
Cartesian CMM
Tool With Integral Sensor (Slide 12)
Tool With Detachable Sensor (Slide 12)
or
Single-Carriage Cartesian CMM
Double-Carriage Cartesian CMM
Light Pen CMM
Articulated Arm CMM
Parallel Link CMM

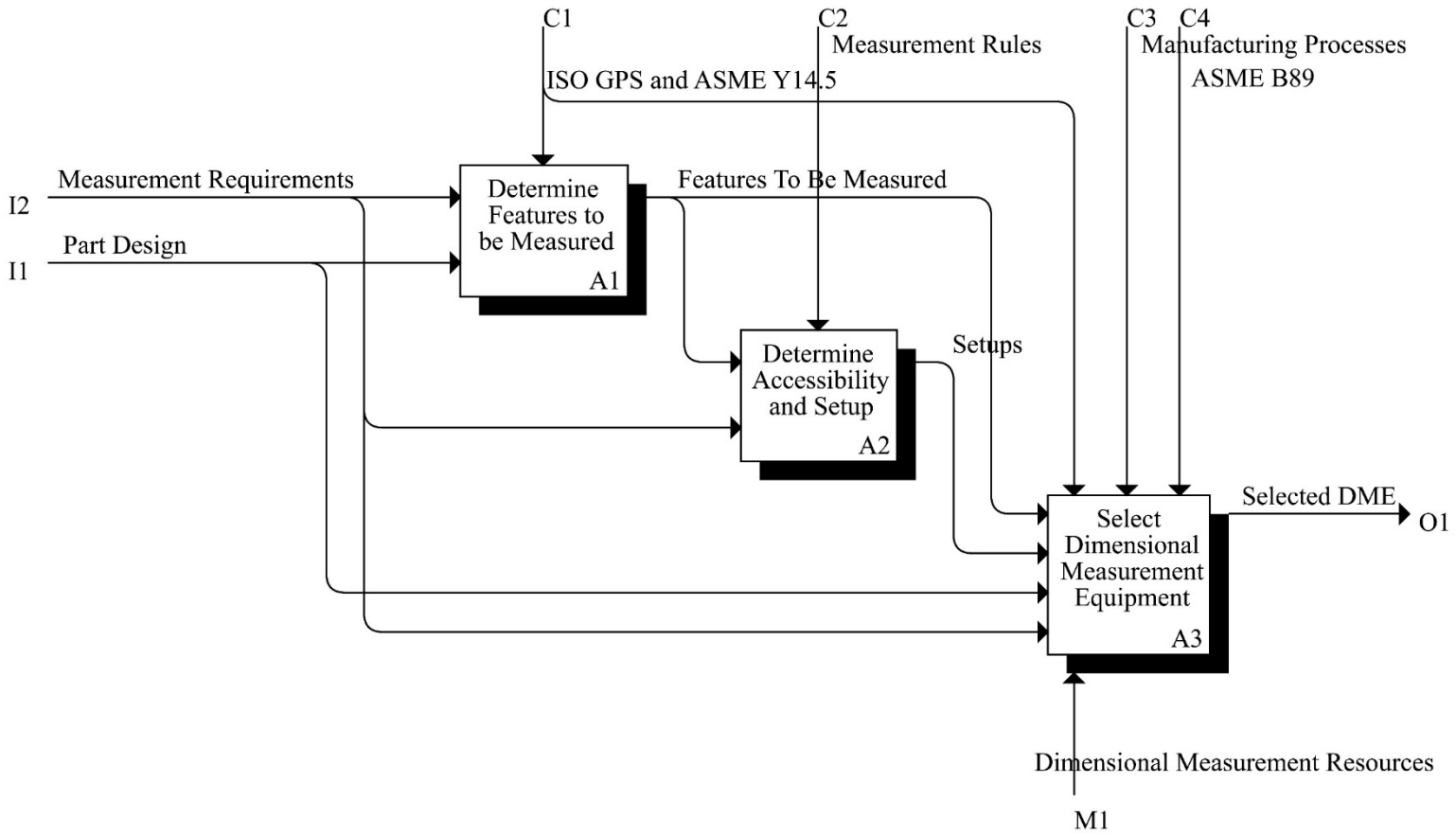

Tool With Detachable Sensor
(Similar structure for Tool With Integral Sensor)
or
Tactile Probe
(Slide 13)
Nontactile Sensor
Magneto Inductive Sensor
or
Laser Triangulation Probe
CCD Camera
Structured Light Sensor
Capacitive Sensor
Confocal Chromatic Sensor


Tactile Probe
and
Probe Body
Stylus
Probe Tip
or
or
or
Indexable Tactile Probe
Fixed Tactile Probe
Straight Stylus
Star Stylus
Ball Tip
Cylindrical Tip

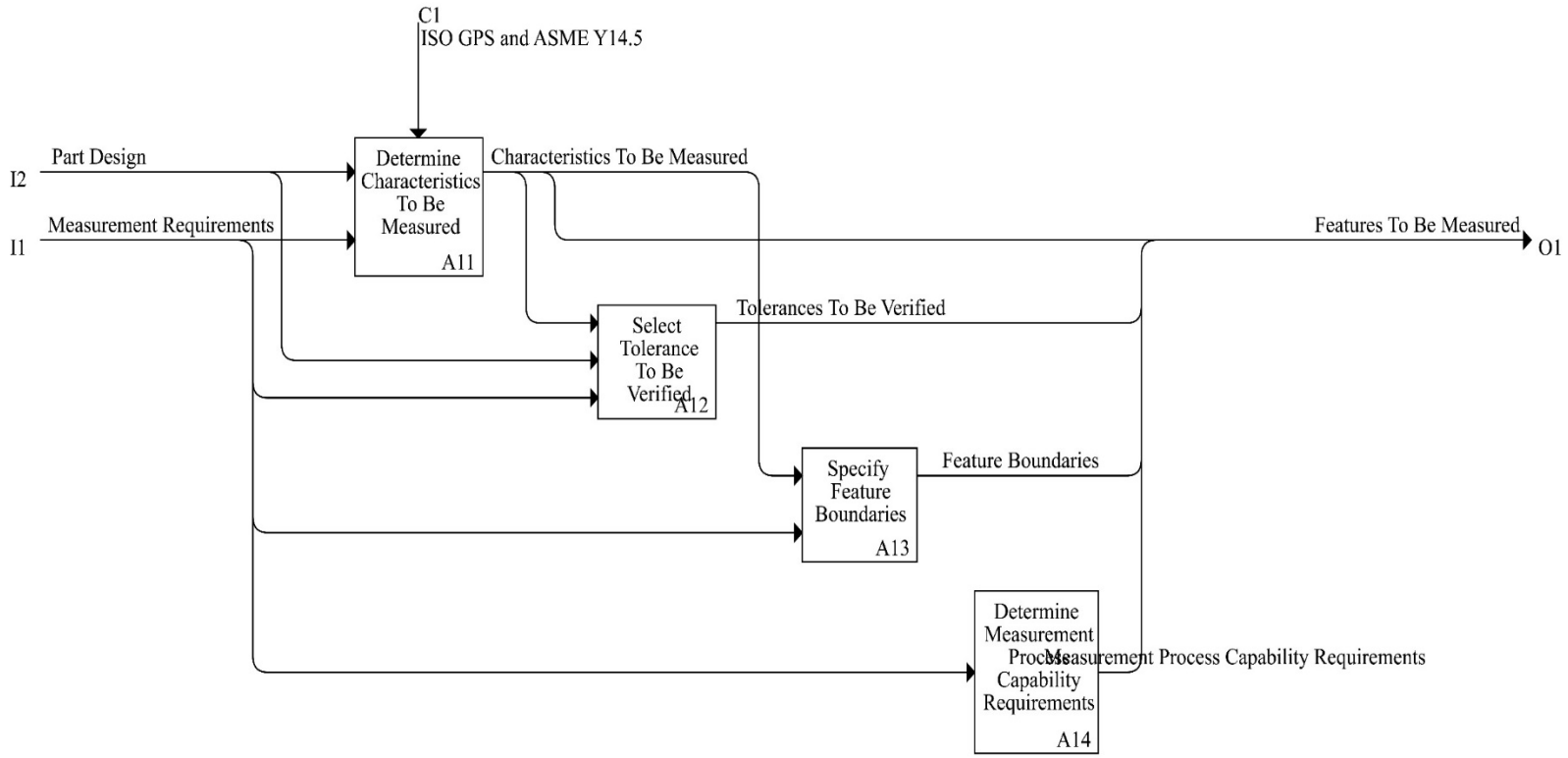
Industry Needs

Rule models for writing metrological rules to establish the relationship between (1) dimensional and geometric characteristics, tolerances, and measurement requirements with (2) choices of dimensional measurement equipment.

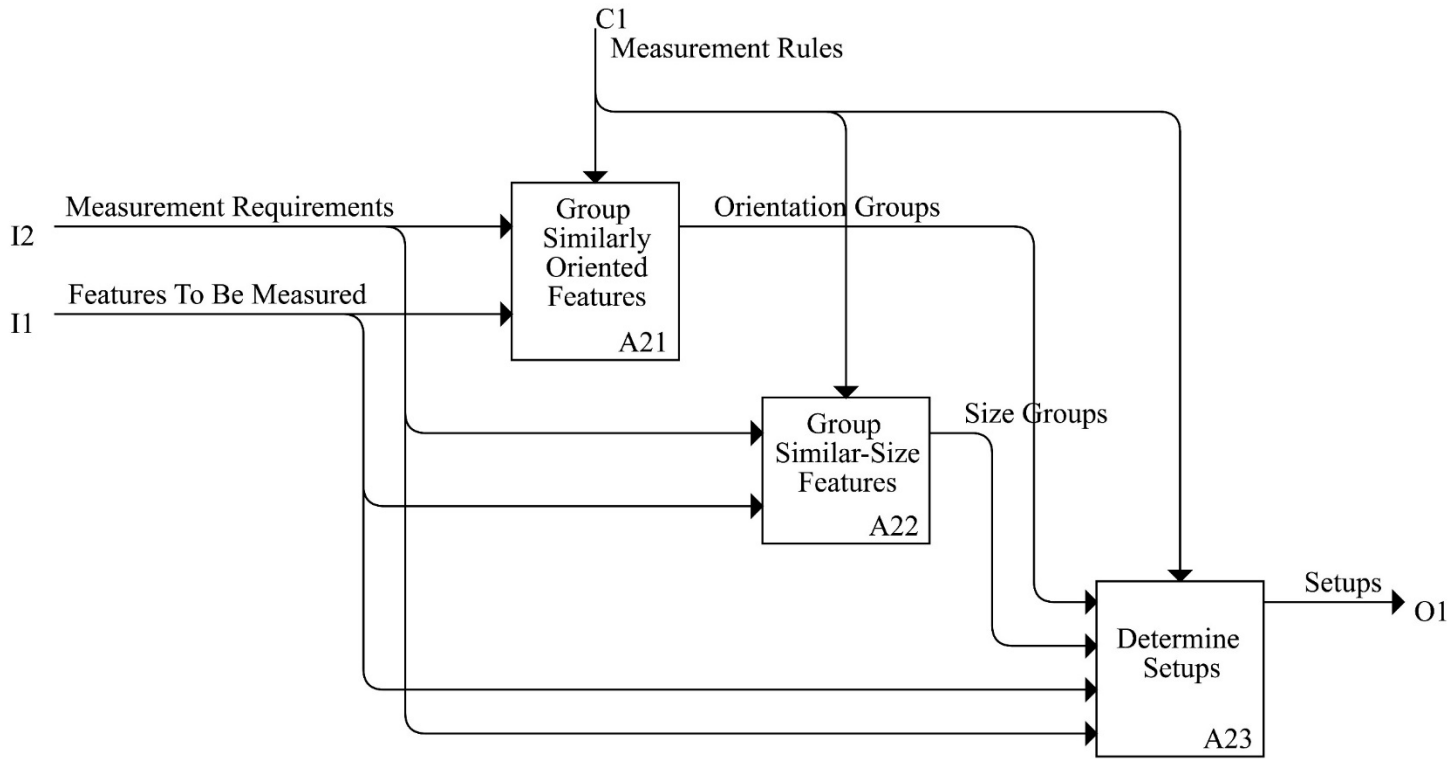
Dimensional Measurement Equipment Selection Process



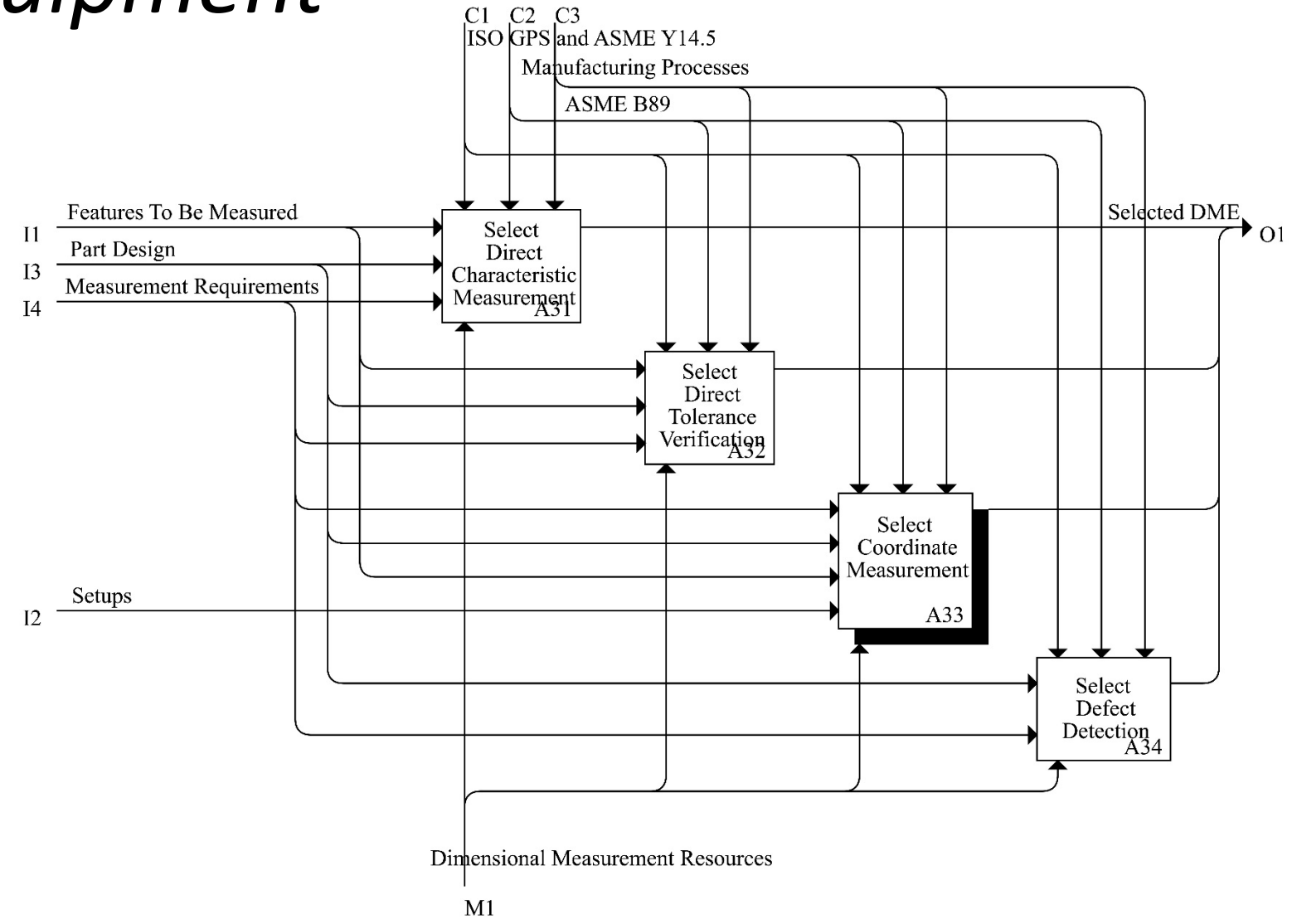
Determine Features to Measure



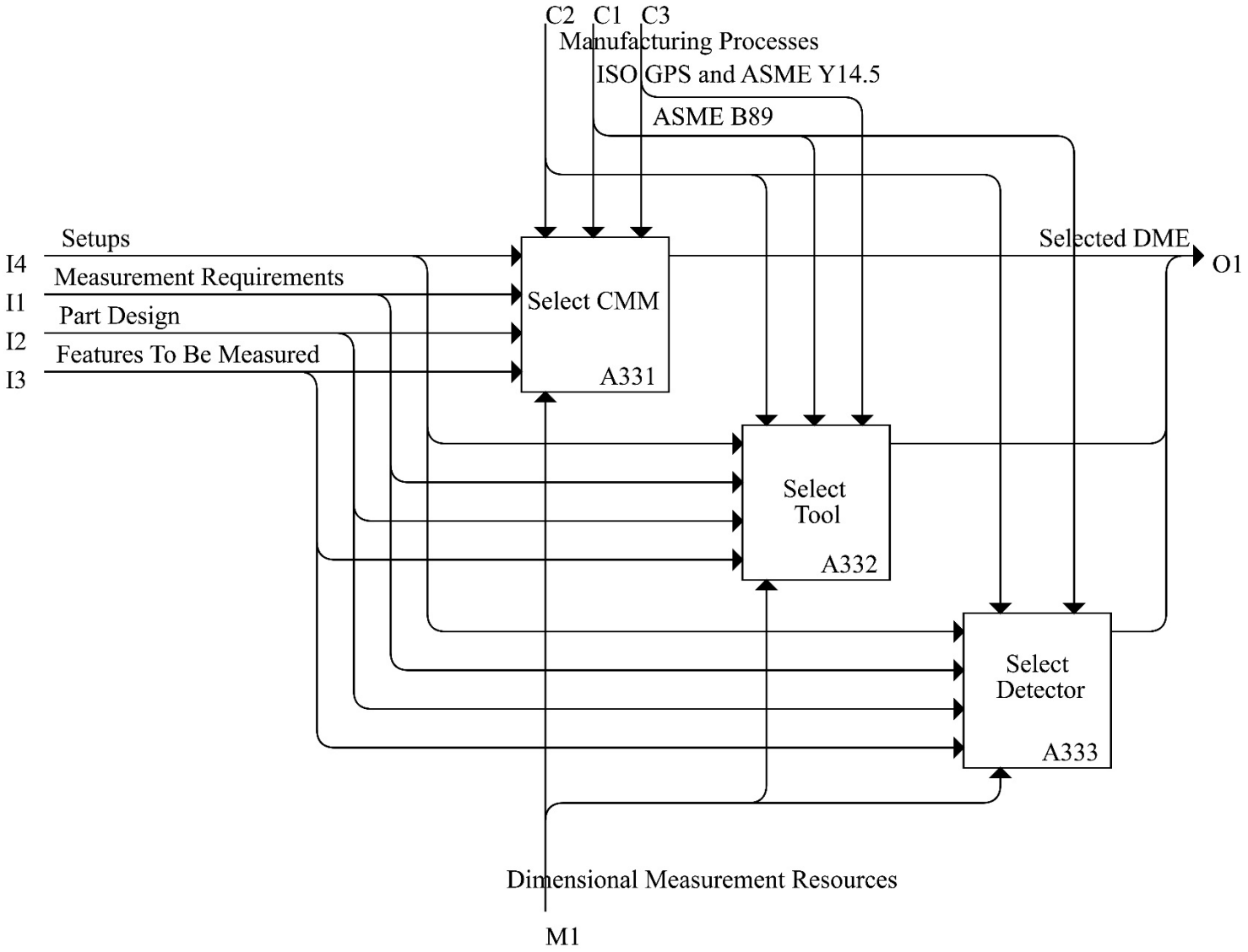
Determine Accessibility and Setups



Select Dimensional Measurement Equipment



Select Coordinate Measuring Machine



Example Rule Types – General Rules

Equipment capability (C)	C = Tightest Tolerance / MPE (Max Permissible Error)
Examples	C >= 10 (Recommended) C >= 4 (OK)

Work Volume Requirement (WR)	WRx = Equipment Work Volume in X / Workpiece Space in X WRy = Equipment Work Volume in Y / Workpiece Space in Y WRz = Equipment Work Volume in Z / Workpiece Space in Z
Examples	WRx >= 1.5 AND WRy >= 1.5 AND WRz >= 1.5

Probe Tip Accessibility (PT)	PT = Smallest Internal Feature Size / Probe Tip Size e.g., PT = SmallestHoleDiameter / TipEndDiameter >= 2
Stylus Accessibility (SA)	SA = Stylus Length / Length of the Deepest Internal Feature e.g., SA = Stylus Length / Length of the Deepest Hole >= 1.5
Orientation Accessibility (OA)	OA in the XY plane= Probe Reachable Orientation in XY > Most Slant Feature Orientation in XY Similarly, OA in the YZ plane and in the ZX plane e.g., OA in XY = Probe Reachable Orientation (45 deg) > Most Slant Hole (20 deg)

Example Rule Types – General Rules

Working Environment Temperature (TR)	TR should be kept in a range e.g., TR = 22 deg C +/- 0.5 deg C
Working Environment Humidity (HR)	HR should be kept in a range e.g., HR = 1 g/cubic meter +/- 0.1 g/cubic meter

Surface Roughness (SR)	SR <= UserDefinedSR e.g., SR <= 100 micro meter (Sa)

Surface Reflectivity (RF)	RF <= UserDefineMaximumSurfaceReflectivity RF >= UserDefineMinimumSurfaceReflectivity

Example Rule Types – Specific Rules

Tactile probe selection

IF (Conditions)	PT >= UserDefinedPT AND SA >= UserDefinedSA AND OA >= UserDefinedOrientation
THEN (Actions)	Select ((FixedTactileProbe or IndexableTactileProbe) AND (StraightStylus or StarStylus) AND (BallTip or CylindricalTip or ConicalTip))

Nontactile probe selection

IF (Conditions)	RF >= UserDefinedMinimumRF AND RF <= UserDefinedMaximumRF
THEN (Actions)	Select (LaserTriangulationProbe OR CCDCamera OR StructuredLightSensor OR ConfocalChromaticSensor OR CapacitiveSensor)

Example Rule Types – Specific Rules

CMM selection

IF (Conditions)	C >= UserDefinedC AND WR >= UserDefinedWR AND IC == UserDefinedIC AND PT >= UserDefinedPT AND SA >= UserDefinedSA AND OA > UserDefinedOA AND TR >= UserDefinedTR AND HR >= UserDefinedHR AND LT < UserDefinedLT AND MT < UserDefinedMT AND A == UserDefinedA AND SR <= UserDefinedSR AND RF >= UserDefinedMinimumRF AND RF <= UserDefinedMaxumumRF
THEN (Actions)	Select TypeofCMM AND (ToolwithDetachableSensor or ToolwithIntegralSensor) AND (TactileProbe or NontactileSensor)

Example Rule Types – Specific Rules

Gage selection for Direct Linear Measurement

IF (Conditions)	C >= UserDefinedC AND WR >= UserDefinedWR AND IC == UserDefinedIC
THEN (Actions)	Select (ULM OR Micrometer OR BoreGage or OpticalComparator)

Optical Gage selection for Direct Angular Measurement

IF (Conditions)	C >= UserDefinedC AND WR >= UserDefinedWR AND IC == UserDefinedIC
THEN (Actions)	Select (Autocollimator OR SineBar or OpticalComparator)

Example Rule Types – Specific Rules

Direct-tolerance verification device selection

IF (Conditions)	C >= UserDefinedC AND WR >= UserDefinedWR AND IC == UserDefinedIC
THEN (Actions)	Select (Go/No-GoGage or OpticalComparator)

Example Rule Types – Specific Rules

Surface defect inspection instrument selection

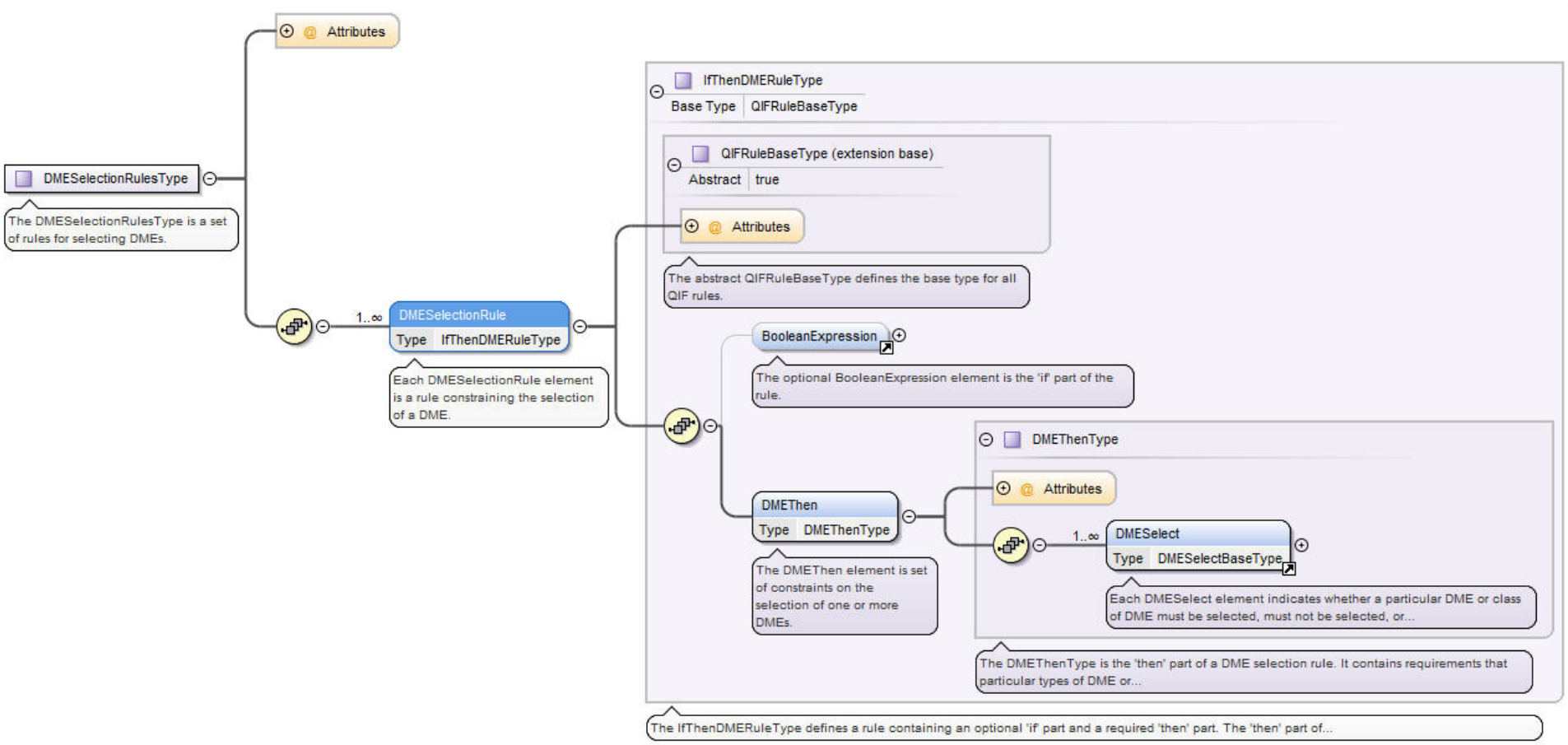
IF (Conditions)	C >= UserDefinedC AND WR >= UserDefinedWR AND IC == UserDefinedIC AND LT < UserDefinedLT AND MT < UserDefinedMT AND A == UserDefinedA
THEN (Actions)	Select (SpecificSurfaceDefectDetectionInstrument)

Beneath surface defect inspection instrument selection

IF (Conditions)	C >= UserDefinedC AND WR >= UserDefinedWR AND IC == UserDefinedIC AND LT < UserDefinedLT AND MT < UserDefinedMT AND A == UserDefinedA
THEN (Actions)	Select (SpecificBeneathSurfaceDefectDetectionInstrument)

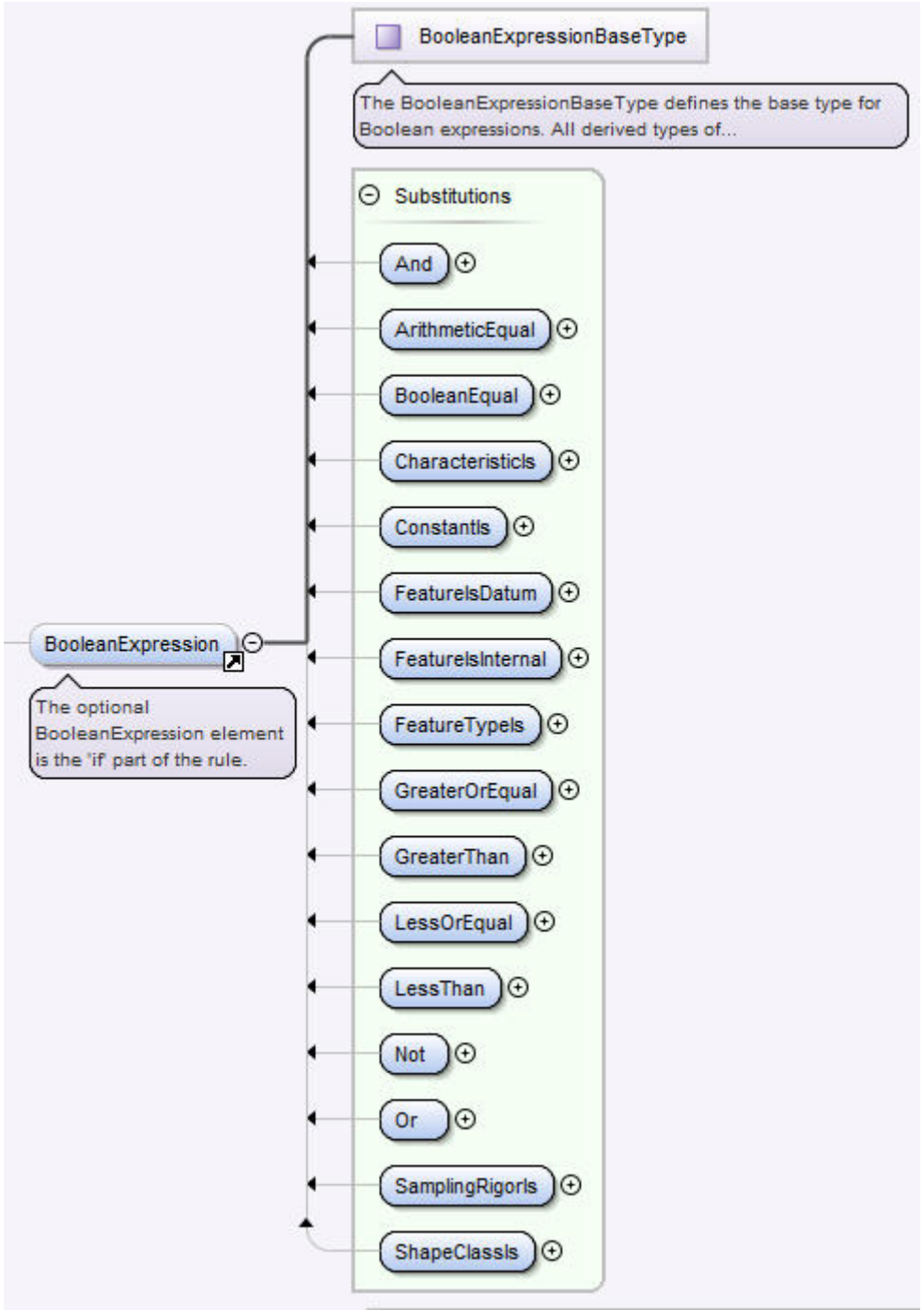
Implemented QIF Rules XML Schema

DMESelectionRulesType

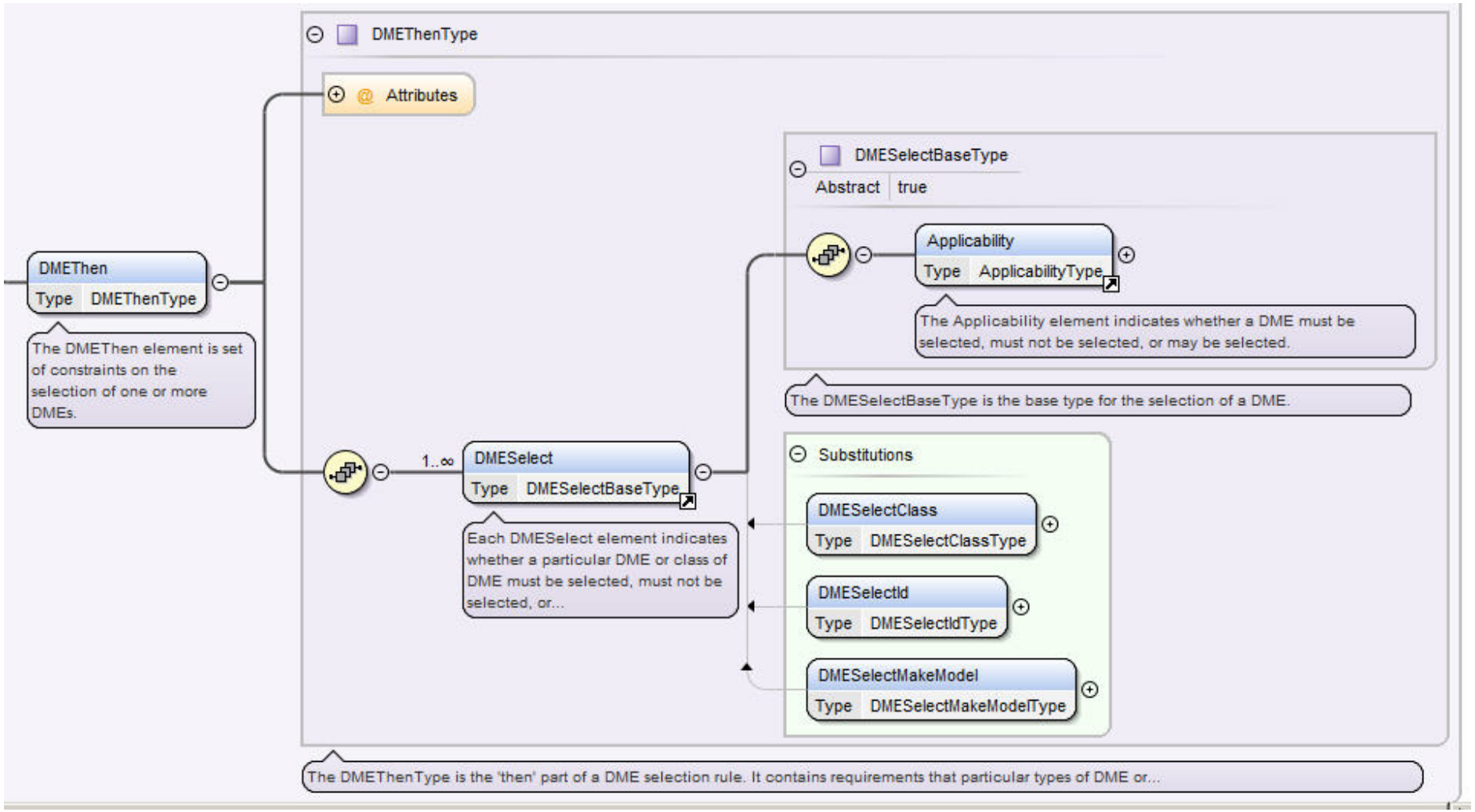


QIF Part 6: Rules Information Model and Schema version 3.0 (final draft)

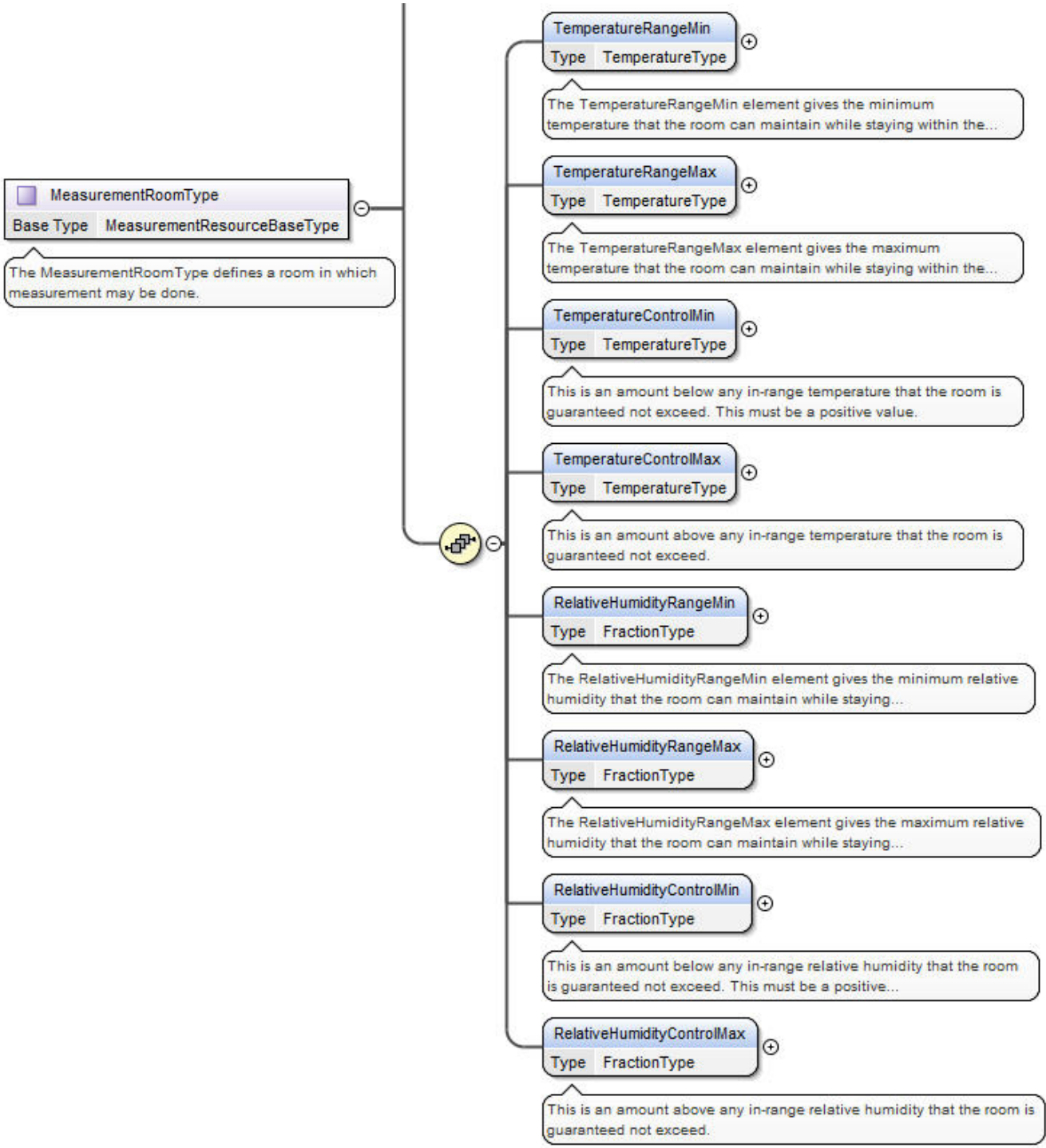
DMEBoolean


BooleanExpressionBaseType
The BooleanExpressionBaseType defines the base type for Boolean expressions. All derived types of...
Substitutions
And
ArithmeticEqual
BooleanEqual
CharacteristicIs
ConstantIs
FeatureIsDatum
FeatureIsInternal
FeatureTypeIs
GreaterOrEqual
GreaterThan
LessOrEqual
LessThan
Not
Or
SamplingRigorIs
ShapeClassIs
BooleanExpression
The optional BooleanExpression element is the 'if' part of the rule.

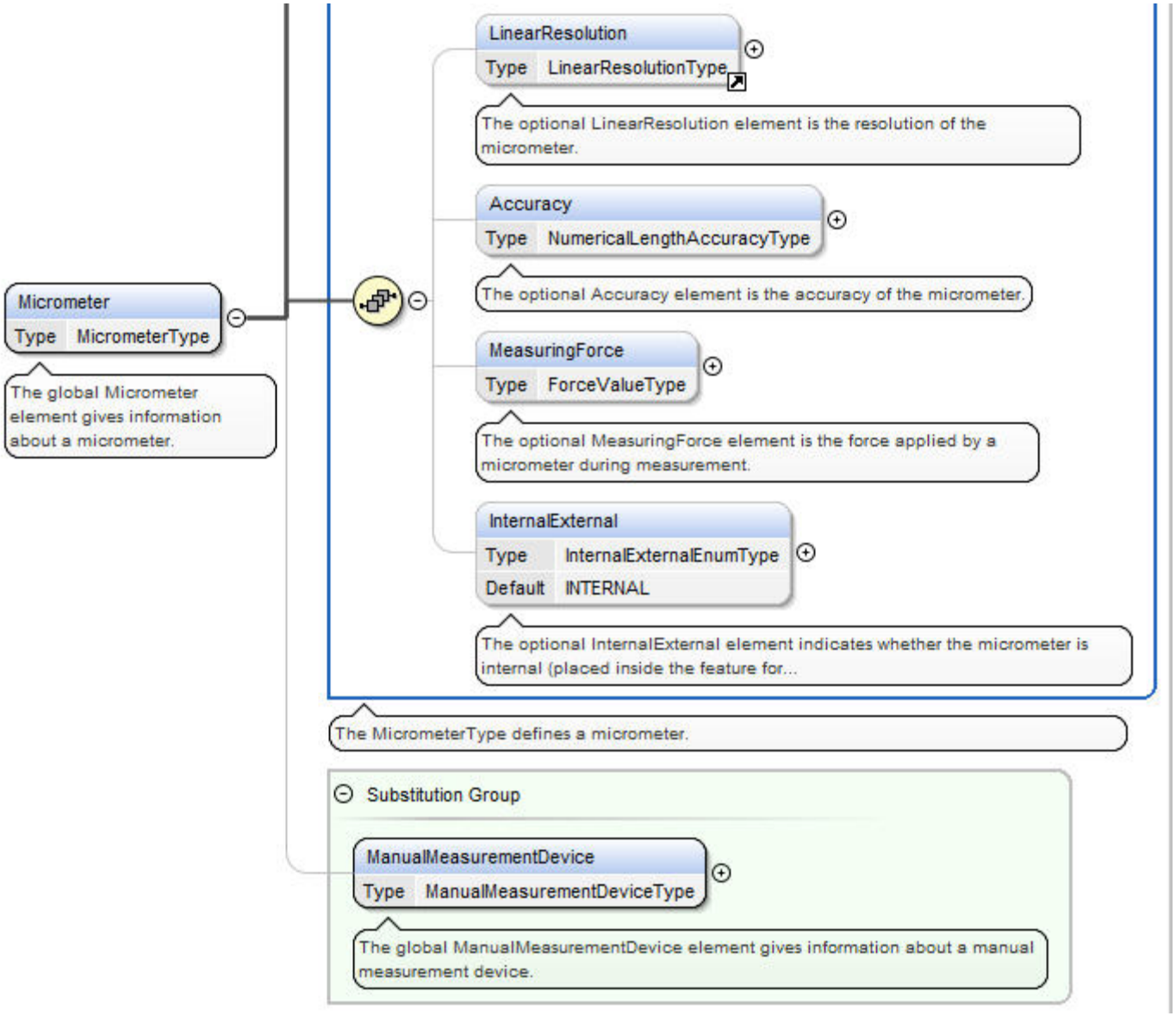
DMEThen


DMEThenType
Attributes
DMEThen
Type DMEThenType
The DMEThen element is set of constraints on the selection of one or more DMEs.
1..∞
DMESelect
Type DMESelectBaseType
Each DMESelect element indicates whether a particular DME or class of DME must be selected, must not be selected, or...
DMESelectBaseType
Abstract true
Applicability
Type ApplicabilityType
The Applicability element indicates whether a DME must be selected, must not be selected, or may be selected.
The DMESelectBaseType is the base type for the selection of a DME.
Substitutions
DMESelectClass
Type DMESelectClassType
DMESelectId
Type DMESelectIdType
DMESelectMakeModel
Type DMESelectMakeModelType
The DMEThenType is the 'then' part of a DME selection rule. It contains requirements that particular types of DME or...

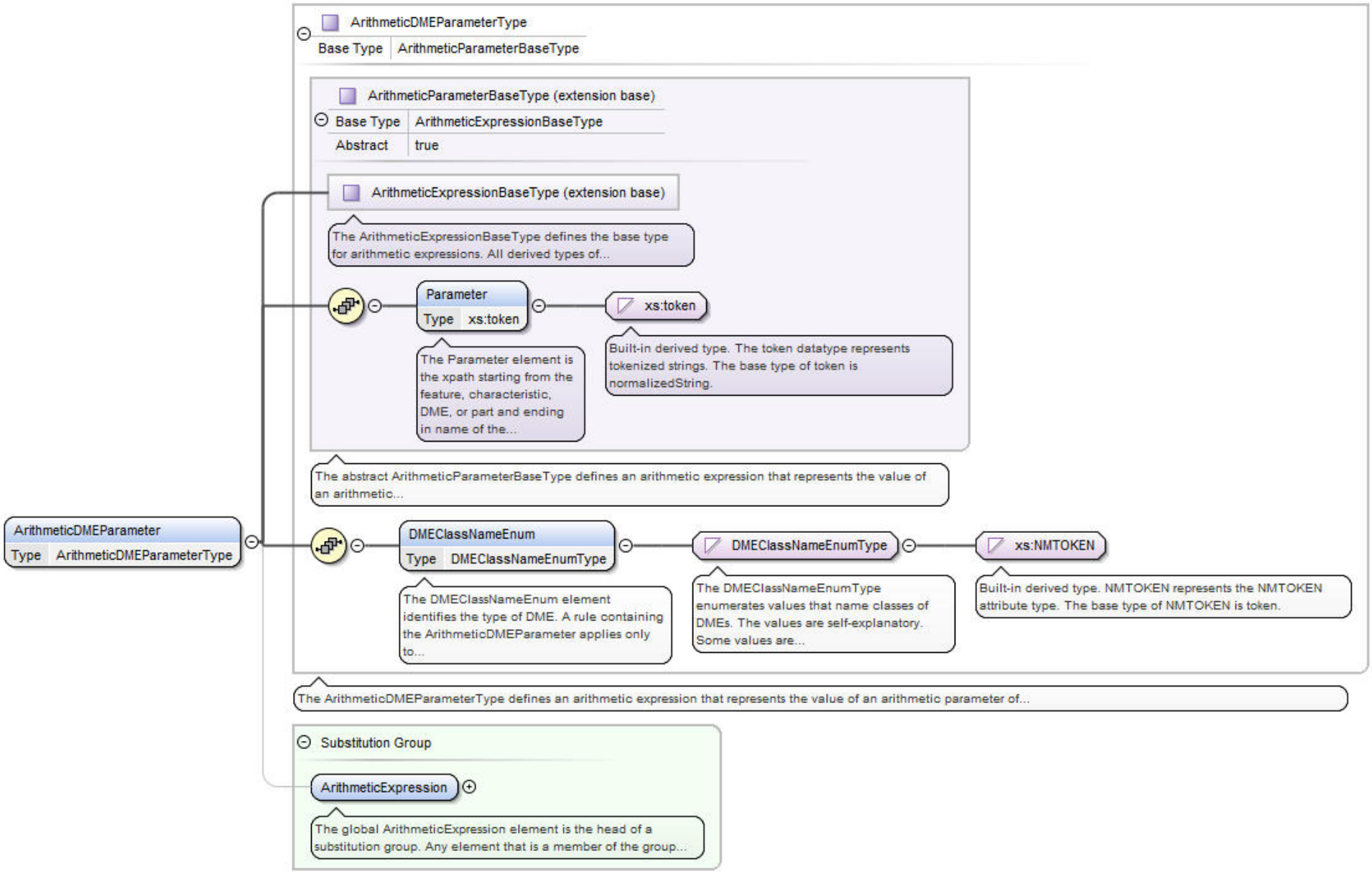
Measurement Room



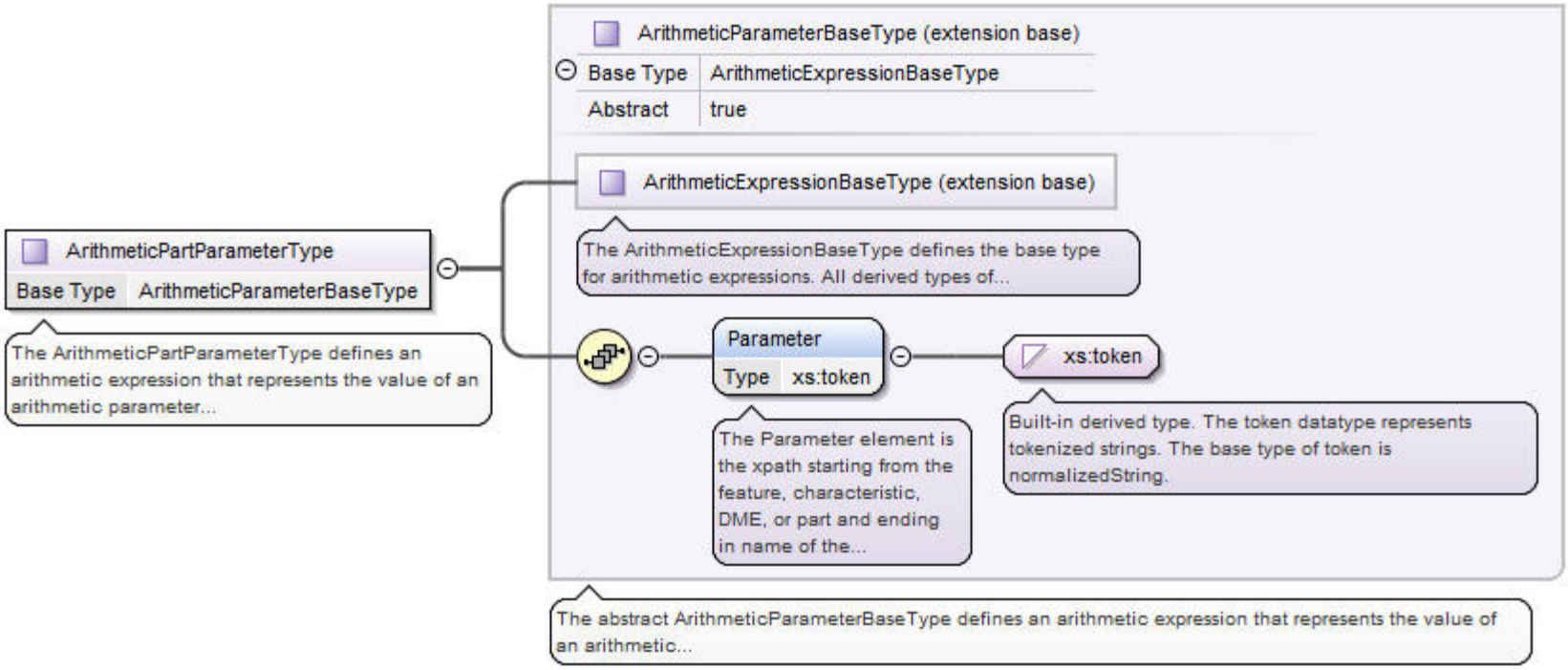
Micrometer


Micrometer
Type MicrometerType
The global Micrometer element gives information about a micrometer.
LinearResolution
Type LinearResolutionType
The optional LinearResolution element is the resolution of the micrometer.
Accuracy
Type NumericalLengthAccuracyType
The optional Accuracy element is the accuracy of the micrometer.
MeasuringForce
Type ForceValueType
The optional MeasuringForce element is the force applied by a micrometer during measurement.
InternalExternal
Type InternalExternalEnumType
Default INTERNAL
The optional InternalExternal element indicates whether the micrometer is internal (placed inside the feature for...
The MicrometerType defines a micrometer.
Substitution Group
ManualMeasurementDevice
Type ManualMeasurementDeviceType
The global ManualMeasurementDevice element gives information about a manual measurement device.

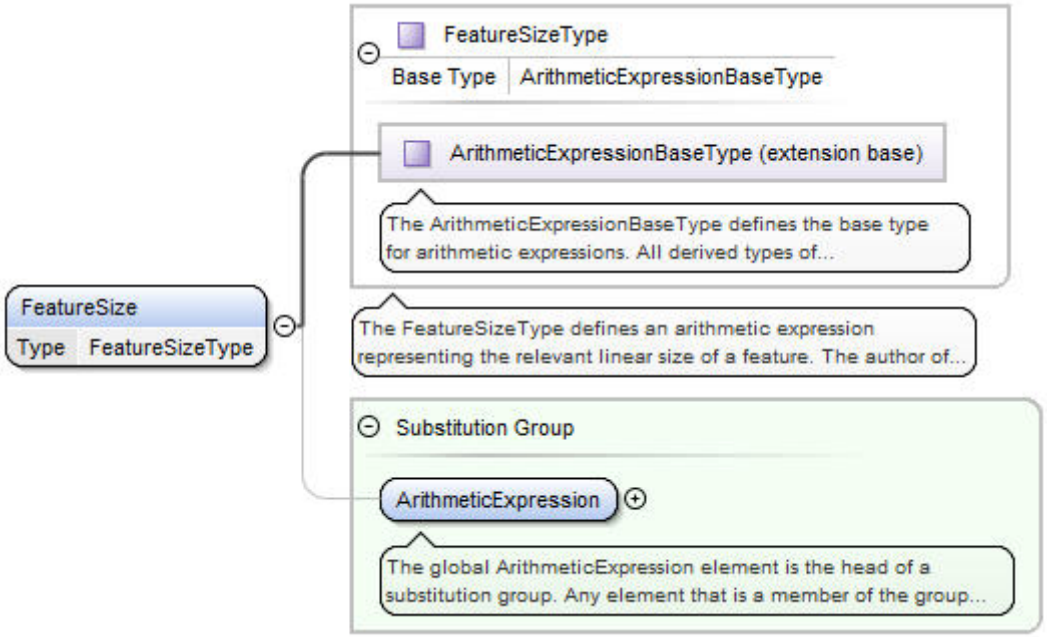
ArithmeticDMEParameter



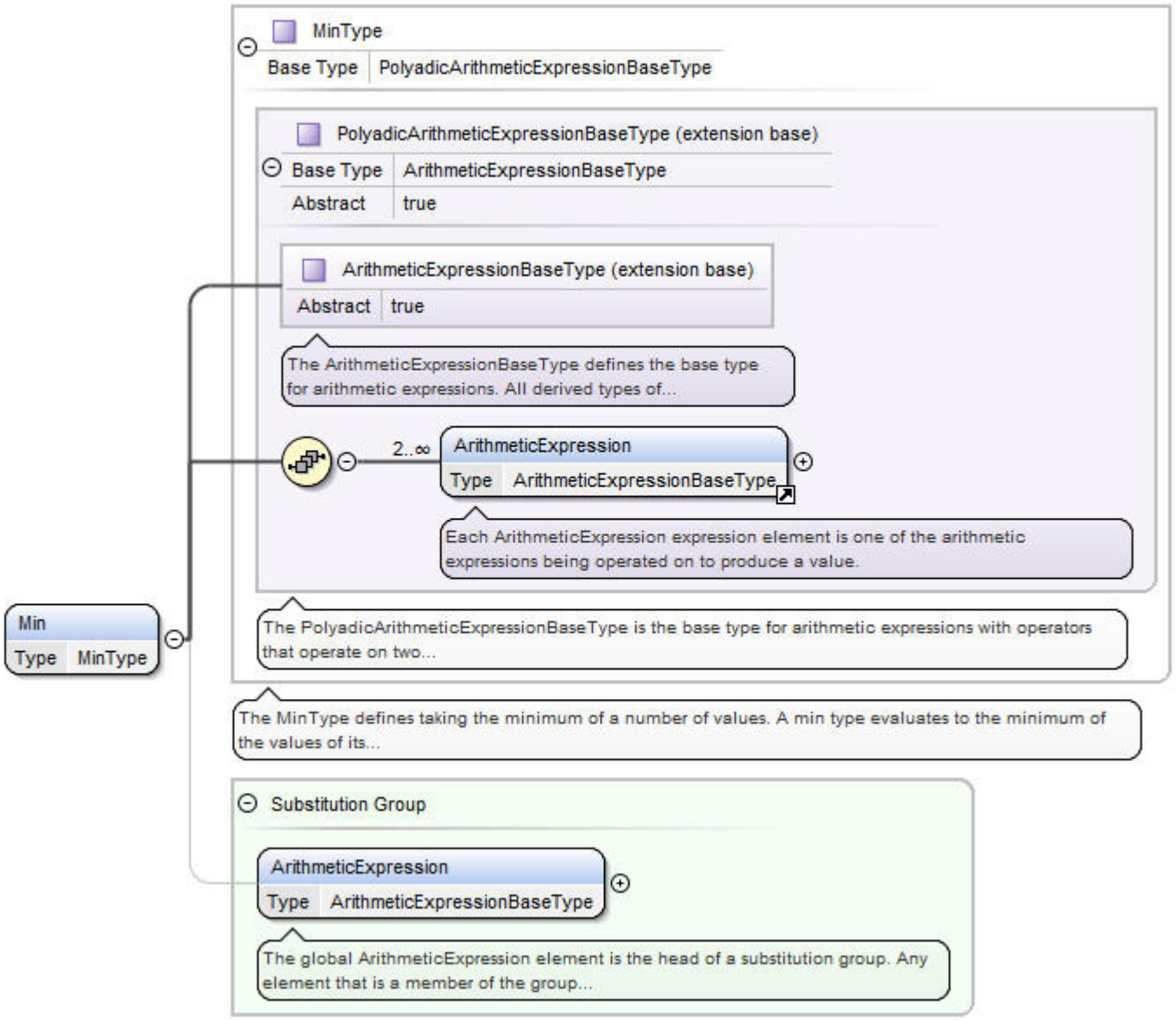
ArithmeticPartParameter



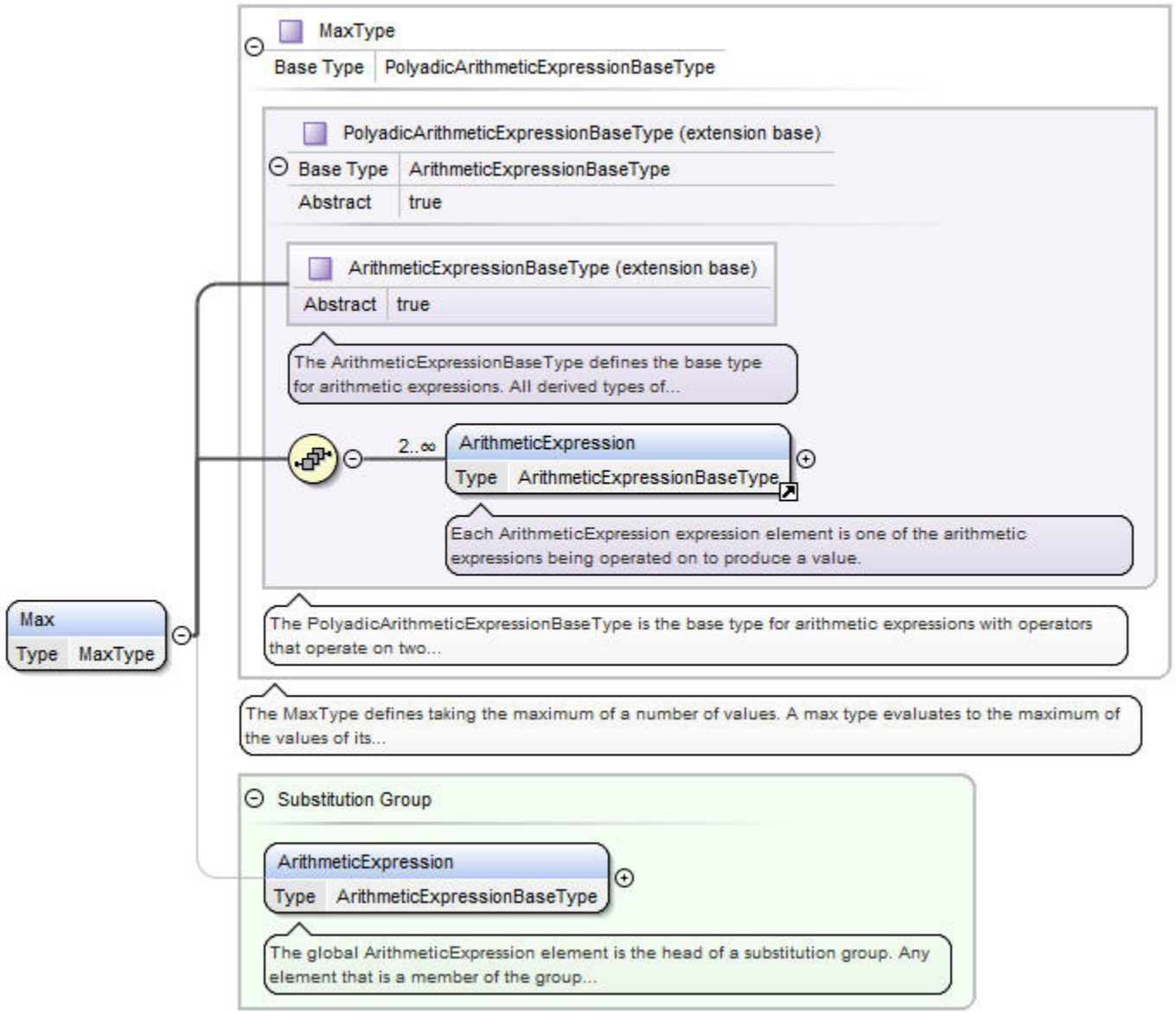
Feature Size



Min


MinType
Base Type
PolyadicArithmeticExpressionBaseType
PolyadicArithmeticExpressionBaseType (extension base)
Base Type
ArithmeticExpressionBaseType
Abstract
true
ArithmeticExpressionBaseType (extension base)
Abstract
true
The ArithmeticExpressionBaseType defines the base type for arithmetic expressions. All derived types of...
2..∞
ArithmeticExpression
Type
ArithmeticExpressionBaseType
Each ArithmeticExpression expression element is one of the arithmetic expressions being operated on to produce a value.
Min
Type
MinType
The PolyadicArithmeticExpressionBaseType is the base type for arithmetic expressions with operators that operate on two...
The MinType defines taking the minimum of a number of values. A min type evaluates to the minimum of the values of its...
Substitution Group
ArithmeticExpression
Type
ArithmeticExpressionBaseType
The global ArithmeticExpression element is the head of a substitution group. Any element that is a member of the group...

Max


MaxType
Base Type
PolyadicArithmeticExpressionBaseType
PolyadicArithmeticExpressionBaseType (extension base)
Base Type
ArithmeticExpressionBaseType
Abstract
true
ArithmeticExpressionBaseType (extension base)
Abstract
true
The ArithmeticExpressionBaseType defines the base type for arithmetic expressions. All derived types of...
2..∞
ArithmeticExpression
Type
ArithmeticExpressionBaseType
Each ArithmeticExpression expression element is one of the arithmetic expressions being operated on to produce a value.
Max
Type
MaxType
The PolyadicArithmeticExpressionBaseType is the base type for arithmetic expressions with operators that operate on two...
The MaxType defines taking the maximum of a number of values. A max type evaluates to the maximum of the values of its...
Substitution Group
ArithmeticExpression
Type
ArithmeticExpressionBaseType
The global ArithmeticExpression element is the head of a substitution group. Any element that is a member of the group...

Instance Example 1

```
<!--
DME resolution must be less than or equal to tolerance times 0.1.
(Rolls-Royce Guide, page 6, section 2.2.3, text)

This rule has no IF part
-->
     <DMESelectionRule>
<DMEThen n="1">
 <DMESelectClass>
  <Must/>
  <DMEClassName>ALLDMES</DMEClassName>
  <ParameterConstraints n="1">
   <DMEParameterConstraint>
<ParameterName>Resolution</ParameterName>
<Comparison>LESSOREQUAL</Comparison>
<Times>
 <ArithmeticConstant val="0.1"/>
 <ArithmeticCharacteristicParameter>
  <Parameter>Tolerance</Parameter>
 </ArithmeticCharacteristicParameter>
</Times>
    </DMEParameterConstraint>
  </ParameterConstraints>
 </DMESelectClass>
</DMEThen>
    </DMESelectionRule>
```

Instance Example 2

```
<!--
If the characteristic is thickness, then a micrometer may be used.
(Rolls-Royce Guide, page 7, Equipment Selection table)
-->
    <DMESelectionRule>
            <CharacteristicIs val="THICKNESS"/>
            <DMEThen n="1">
             <DMESelectClass>
              <May desirability="1"/>
              <DMEClassName>MICROMETER</DMEClassName>
             </DMESelectClass>
            </DMEThen>
     </DMESelectionRule>
```

Instance Example 3

```
<!-- If Equipment Effective Working Volume  >=  Part Bounding Box Volume * 1.5 Then a Universal Device may be selected.-->
<DMESelectionRule>
<GreaterOrEqual>
  <Times>
   <ArithmeticDMEParameter>
    <Parameter>CartesianWorkingVolume/XAxisLength</Parameter>
    <DMEClassNameEnum>UNIVERSAL_DEVICE</DMEClassNameEnum>
   </ArithmeticDMEParameter>
   <ArithmeticDMEParameter>
    <Parameter>CartesianWorkingVolume/YAxisLength</Parameter>
    <DMEClassNameEnum>UNIVERSAL_DEVICE</DMEClassNameEnum>
   </ArithmeticDMEParameter>
   <ArithmeticDMEParameter>
    <Parameter>CartesianWorkingVolume/ZAxisLength</Parameter>
    <DMEClassNameEnum>UNIVERSAL_DEVICE</DMEClassNameEnum>
   </ArithmeticDMEParameter>
  </Times> <Times>
   <ArithmeticConstant val="1.5"/>
   <ArithmeticPartParameter>
    <Parameter>PartFamily/MinimumBoundingBox/Length</Parameter>
   </ArithmeticPartParameter>
   <ArithmeticPartParameter>
    <Parameter>PartFamily/MinimumBoundingBoxWidth</Parameter>
   </ArithmeticPartParameter>
   <ArithmeticPartParameter>
    <Parameter>PartFamily/MinimumBoundingBoxHeight</Parameter>
   </ArithmeticPartParameter>
  </Times>
</GreaterOrEqual>
<DMEThen n="1">
  <DMESelectClass>  <May/>  <DMEClassName>UNIVERSAL_DEVICE</DMEClassName>
  </DMESelectClass>
</DMEThen>
</DMESelectionRule>
```

Conclusions & Future Work

- Activity modeling is an effective way for identifying activities, inputs, controls, mechanism, and outputs for determining characteristics/features to be measured.
- The new DME Selection Rule Types should meet the needs of users to share DME selection rules among heterogenous systems.
- Pilot implementations of the model are undergoing. Feedback will be provided to the QIF Rules Working group.

QIF Rules Information Model and Schema v3.0 (draft)

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QIF™ Quality Information Framework