Proceedings of the ASME 2017 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference
IDETC/CIE 2017
August 6-9, 2017, Cleveland, Ohio, USA

DETC2017-68013

DEVELOPING AN ACTIVITY MODEL FOR SELECTING DIMENSIONAL-METROLOGY SYSTEMS IN INSPECTION PLANNING

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ABSTRACT

This paper describes an activity model that represents activities and information flow in dimensional metrology systems based on design information and measurement requirements from manufacturers. The purpose of developing the activity model is to facilitate measurement equipment selection rules and conformity decision rules development. The rules can be for users to plan a measurement process using functionally complex and highly capable dimensional measurement equipment and measurement software systems. This activity model provides a basis for developing a rule model as a part of the Quality Information Framework (QIF) standard.

1 INTRODUCTION

As measurement resources are getting more capable, accurate, and complex, manufacturing industry needs to have deeper knowledge on selecting measurement resources so that measurement resource selection can be automated. The concept of measurement resources in this paper includes dimensional measuring equipment and fitting algorithms used in dimensional measurements. Dimensional measuring equipment is any type of hardware used in a measurement process, for example, coordinate measuring machines, fixtures, gages, probes, probe extensions, styli, and probe tips. Measurement devices include instruments having all the components needed for measuring parts, e.g., scanner, laser tracker, and theodolite. Gages include block gages, go/no-go gages, depth gages, and bore gages. Fitting algorithms are used to generate substitute features from measured points. The selection is based on characteristics, tolerances, and datums of the part to be measured. The activity model in this paper describes activities of determining what characteristics and features to be measured, measurement resources selection, and conformity. This activity model is developed also for the Quality Information Framework (QIF) Rules Types [QIF 2016].

The scope of this work is an activity model for determining what to measure and how to measure. What to measure includes dimensional and geometric characteristics [ISO 17450-1 and ISO 25378], tolerances [Y14.5 2009, ISO 1101], metrology features [Y14.5 2009, ISO 17450-3], and datums [Y14.5 2009, ISO 5459]. What to measure is commonly associated with measurement requirements on measuring equipment [ISO 14978]. How to measure includes measurement strategy and selecting dimensional-metrology systems, such as coordinate measuring machines, dimensional measurement devices, and hand-held gages. Also within the scope of this activity model are rules for determining conformity or nonconformity [ISO 14253-1] after measuring the workpiece. Activities that are out of scope include specifying required operator skills, determining when to measure, estimating measurement cycle time, and deciding where to measure (the location of a specific laboratory, shop, or factory). The information identified in the activity model is used in developing the rules model for generating if-then rules for measurement resource selection, measurement strategy selection, and measurement conformity decisions, including risk analysis.

QIF Rules is a component of the QIF suite of standards and is the subject of this paper. Measurement programs (called QIF Execution) is another element of the QIF suite, based on the Dimensional Measuring Interface Standard (DMIS) standard [DMIS]. Several QIF implementer corporations use QIF seamlessly with the DMIS standard, even though DMIS is not modeled in QIF. Converting DMIS semantic content into a format compliant to World Wide Web Consortium (W3C) standards is a future goal.

A few requirements for dimensional metrology equipment selection are available [Muelaner 2010 and Toteva 2014]. Also, the ISO Geometric Product Specification (GPS) standards suite has dimensional and geometric characteristics for defining measurands. GPS has descriptions of dimensional metrology equipment and fitting algorithms.

This paper describes an activity model for describing the process of measurement resources selection. Section 2 reviews literature, including standards, on resources, uncertainty, instrument selection, and smart manufacturing. Section 3 describes selection activities and their sub-activities, including input, output, control, and mechanism data. Section 4 concludes the paper.

2 REVIEW OF THE STATE OF RELATED RESEARCH AND STANDARDS

2.1 Digital Thread for Smart Manufacturing

The digital thread is a term to describe the flows of digital data between engineering, manufacturing, business processes, and across supply chains [Barnard Feeney 2015]. In a manufacturing context, the digital thread is a way for different machines in a manufacturing process to all follow the same set of digital instructions; where deviations are caught automatically, which ensures the end-product is the same as the original design [Hedberg 2016]. Industry has used three-dimensional (3D) Computer-Aided Design (CAD) models for several decades to support faster product-design cycles. The use of CAD models has helped industry analyze a design in a virtual environment and capture the knowledge and design intent effectively. However, industry then strips the model of a significant portion of its value by generating a two-dimensional (2D) static drawing.

In a survey, a finding is that 85 % of respondents use a 3D CAD model in some way to communicate in the supply chain [Ruembler 2016]. Removing paper completely from the product lifecycle may reduce the cycle time 75 % on average [Hedberg 2016]. For these reasons, industry is pushing for processes that are simply model only – the realization of the digital thread. The models would capture all the knowledge and design intent from the decisions that were made in building the model. This push to make models “smart” would enable better decision making, better requirements compliance, and a more tightly integrated product lifecycle.

2.2 The Quality Information Framework

QIF is an American National Standards Institute (ANSI) standard, developed by the Dimensional Metrology Standards Consortium (DMSC). QIF 2.1 is the current version. It is a complete set of digital information models for all key components for realizing successful dimensional measurement, namely, quality planning, measurement resources, measurement rules, measurement programs, measurement results, and measurement statistics, viz. Statistical Process Control (SPC). Several advanced metrology solution providers have implemented QIF in production. The QIF is modeled compliant to a suite of World Wide Web Consortium (W3C) standards, including XML, XSDL, and XSLT, making it highly suitable for software implementations in Web browsers on multiple hardware platforms.

QIF 2.1 is a XML schema-based information model divided into several separable components, which together realize an explicit and full definition of metrology information throughout the entire dimensional metrology lifecycle. QIF contains its own unique Model-Based Definition (MBD) with semantically associated Product and Manufacturing Information (PMI), including feature-based tolerances. QIF enables cost-reducing interoperability between different business units within and among corporations and throughout the supply chain, as well as reducing the cost of acquisitions and mergers. QIF addresses a growing number of important use cases including first-article inspection, e.g., AS9102 [AS9102], and other documentary quality reporting standards.

2.3 Review of Related Research in Measurement Resources Selection

This section reviews published papers on accessibility, design to metrology, instrument selection, measurement planning, decision on conformity, and practice. Feature orientations and how to group them have been analyzed for using a coordinate measuring machine to measure workpieces with multiple features in various orientations [Vafaeesefat 2000]. This analysis can be used as a basis for accessibility rules development. A review of data transferring from QIF MBD and tolerances to dimensional metrology has identified how model data, including tolerances, can be used for measurement planning [Morse 2016]. Guides have been presented for selection of large parts measurement using coordinate measuring machines (CMMs) [Muelaner 2010]. The guides are good sources for developing a set of CMM selection rules. Similar research on categorization of gages, CMMs, standards, and usages shows measurement equipment selection rules are beneficial to measurement planning [Toteva 2014]. An overview of coordinate measurement strategy identifies rules for creating probing or sensing strategies [Flack 2014]. Another review of strategy planning for coordinate measurement identifies conditions and actions for strategic planning rule development [CMS 2016]. Practical matters in CMM probing workpieces have been reviewed, and the paper identified probing requirements and probe selections [Flack 2014b]. An industrial categorization of dimensional measurement equipment identifies equipment capabilities and applications [Rolls-Royce 2015]. Another industrial practice on creating measurement strategy is applicable to developing probing rules [Lockheed 2010]. Finally, both uncertainty on measuring machine performance [Birch 2003] has been reviewed, and measured workpiece conformity to the design specification and acceptance/rejection risk have been analyzed [Phillips 2014]. From this review, accessibility, measurement equipment selection, and measurement process planning rules can be developed.

2.4 Relevant Standards

QIF allows the user to designate the standards set that applies to a QIF instance file. The choices expected to be used most frequently are ASME Y14.5 and ISO 1101 (each of which allows any of three different version years.) The ISO Geometric Product Specification (GPS) is a set of smaller documents linked by ISO 1101 that are related standards for dimensional and geometric product specifications and verification [Srinivasan 2008, ISO 8015]. GPS has the following standards that are applicable to the dimensional measurement rule models development. Tolerance-, feature-, and datum-related standards can be used to define conditions of workpieces [ISO 1101, ISO 5459]. Dimensional and geometric characteristics are what to be measured [ASME Y14.5, ISO 25378]. A series of CMM-related standards specify coordinate measurement, uncertainty, and machine performance verification [ASME B89.4.10360.2-2008, ASME B89.4.22, ISO 10360-1, ISO 10360-2]. Also, ANSI B89.7.3.2 is a guide to evaluating measurement uncertainty [B89.7.3.2]. A subset of ISO GPS is related to gages, devices, uncertainties, and measured features [ISO 17450-1, ISO 17450-2, ISO 17450-3]. Terms and fundamental concepts on general measurement equipment are useful to develop rules [ISO 14978]. There is another set of standards on gages and devices regarding gage and device descriptions, decision rules for conformity and nonconformity, and measurement uncertainty statement that can be used for rules development [ISO 14253-1, ISO 14253-2, ISO 14253-3, ISO 14253-4, ISO 14253-5, ISO 14253-6]. Most GPS categories can be tabulated to show their inter-relationships [ISO 14638]. ANSI has a standard on measurement process planning that describes high-level process planning, equipment selection, and probing strategy [B89.7.2]. Finally, measurement process capability can be specified using statistical methods. The selection of equipment should be based on the process capability [ISO 22514-1, ISO 22514-7].

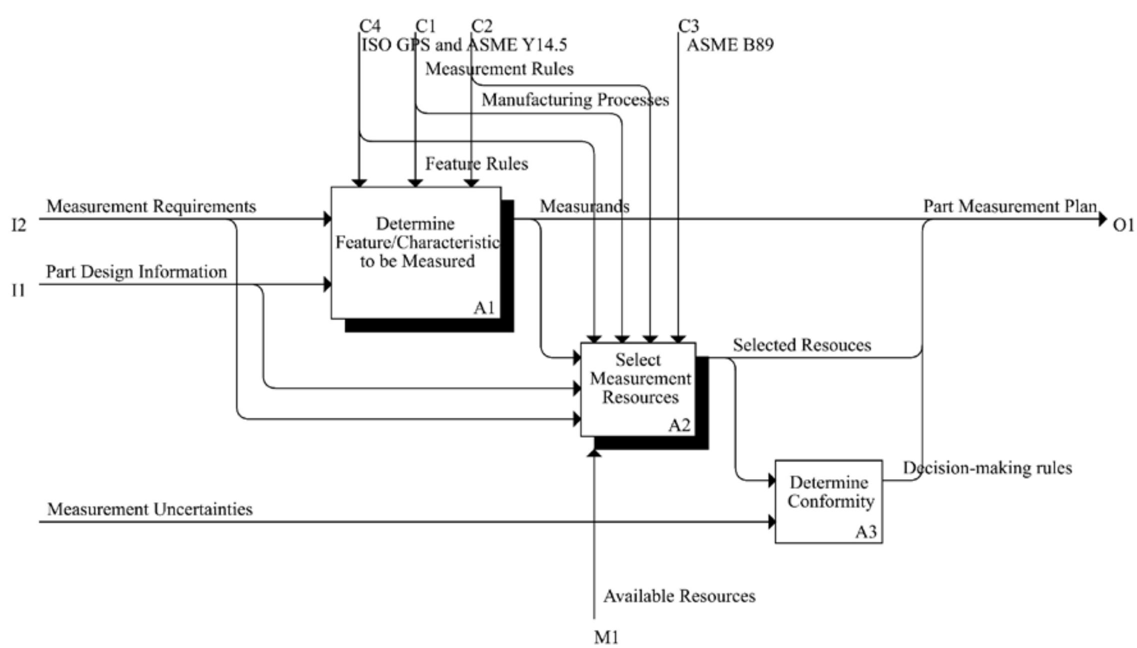

Figure 1 Dimensional Measurement Planning

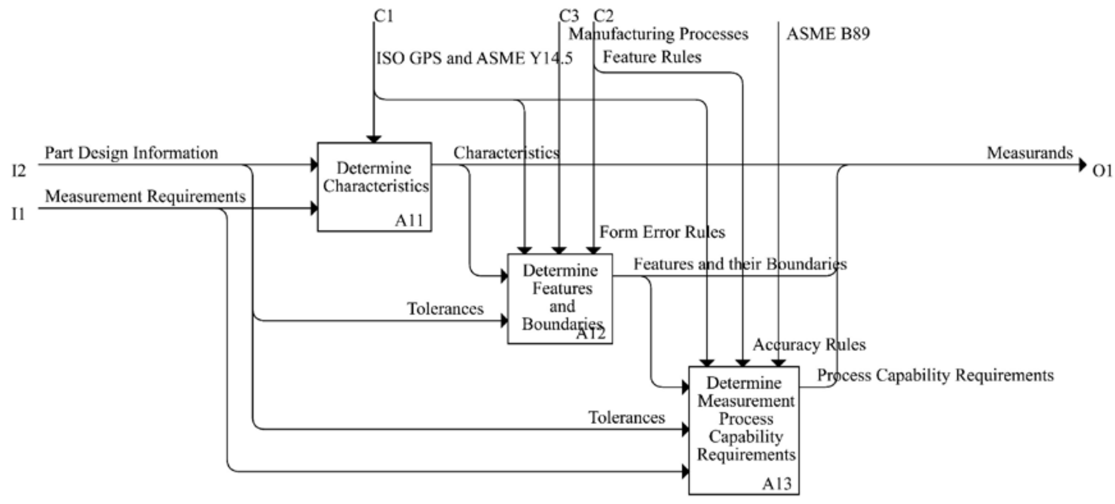

Figure 2 Determine characteristics and features to be measured

2.5 Gaps Analysis

Other than the QIF Rules model, there are no rules models for users to define metrological rules. The research papers and standards reviewed above are the basis for extending the QIF rules model to enhance users' ability to write rules establishing the relationship between (1) dimensional and geometric characteristics and (2) metrological activities and choices, including rules for selecting dimensional measurement equipment.

3. QIF RULES ACTIVITY MODEL

To understand the rule requirements and data flows, we decomposed the measurement planning activity into sub-activities in diagrams using the IDEF0 (Integrated Definition

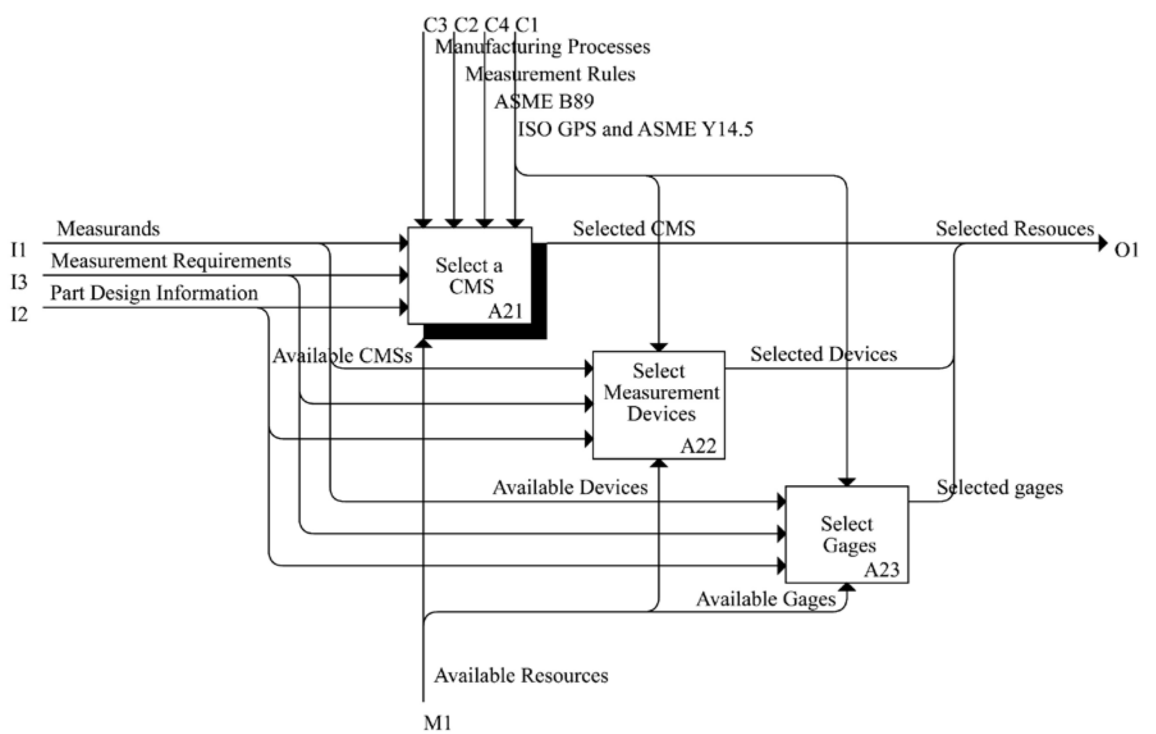

Figure 3 Select Measurement Resources

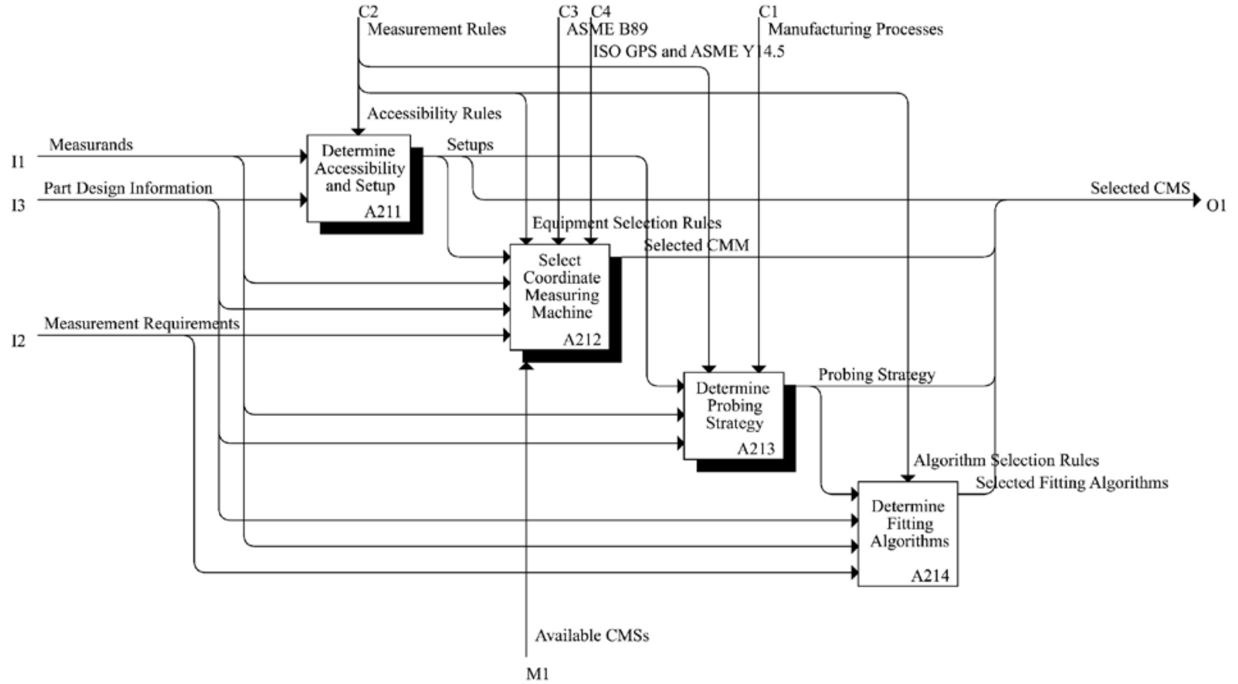

Figure 4 Select coordinate measuring system

for Functional Modeling - the 0th level) methodology [IDF0 2011].

Note that a diagram consists of rectangles and arrows. An activity is represented by a rectangle. When the rectangle is shaded, it means that the activity is decomposed into sub-activities. Input data is consumed from the left by the activity and transformed into output data, which comes out on the right. An output represents the data or material resulting from the activity. Control and constraint data coming from the top are used to regulate the activity. Resource and mechanism data coming from the bottom can be software, hardware, and/or data that support the execution of the activity.

3.1 Dimensional Measurement Planning Activity

This activity can be decomposed into three sub-activities. Figure 1 shows these three A1, A2, and A3.

Activity A1 is to determine characteristics and features to be measured. They are the “what to be measured.” A1 has two inputs: Measurement Requirements and Part Design Information. Measurement requirements are specified by a measurement process planner and specify what dimensional and geometric characteristics are to be measured, e.g., width, length, diameter, position, flatness, roundness, and cylindricity. Features are geometric entities with which the characteristics are associated, e.g., slot, cylinder, plane, and circle. These characteristics and features are from design information specified in a CAD model, QIF Part Design, or drawing. Parameters that control A1 are ISO GPS and ASME Y14.5, Measurement Rules, and Manufacturing Processes. Measurement rules are a set of rules used by A1. Feature rules is a subset of measurement rules for determining features to be measured. Finally, the output of A1 is Measurands that has features and their boundaries for using instruments to measure characteristics. Measurands are one of three elements of a Part Measurement Plan. A1 can be further decomposed and has sub-activities.

A2 is to select measurement resources, based on measurands. For selecting measurement resources, ASME B89 standards [B89.7.2, B89.7.3.2] are used with ISO GPS and others as control parameters for A2. The mechanism parameter is available resources. Available resources can be resources in possession, resources in commercial catalogues, and resources that can be custom-made. The output from A2 is Selected Equipment. It includes coordinate measuring machines, probes, tools, and probe tips, measurement devices, and gages. A2 can further decomposed and has sub-activities.

A3 is to Determine Conformity. It has one output: Decision Making Rules. These rules are used for users to determine whether the part can be accepted or should be rejected, and risks associated with the decision. A3 is not further decomposed and has no sub-activities.

3.2 An automotive engine assembly plant

Activity A1 is decomposed into three subactivities: A11, A12, and A13. Figure 2 shows that decomposition.

Activity A11 is to determine Characteristics. This is based on Measurement Requirements that specify which characteristics need to be measured against what tolerances.

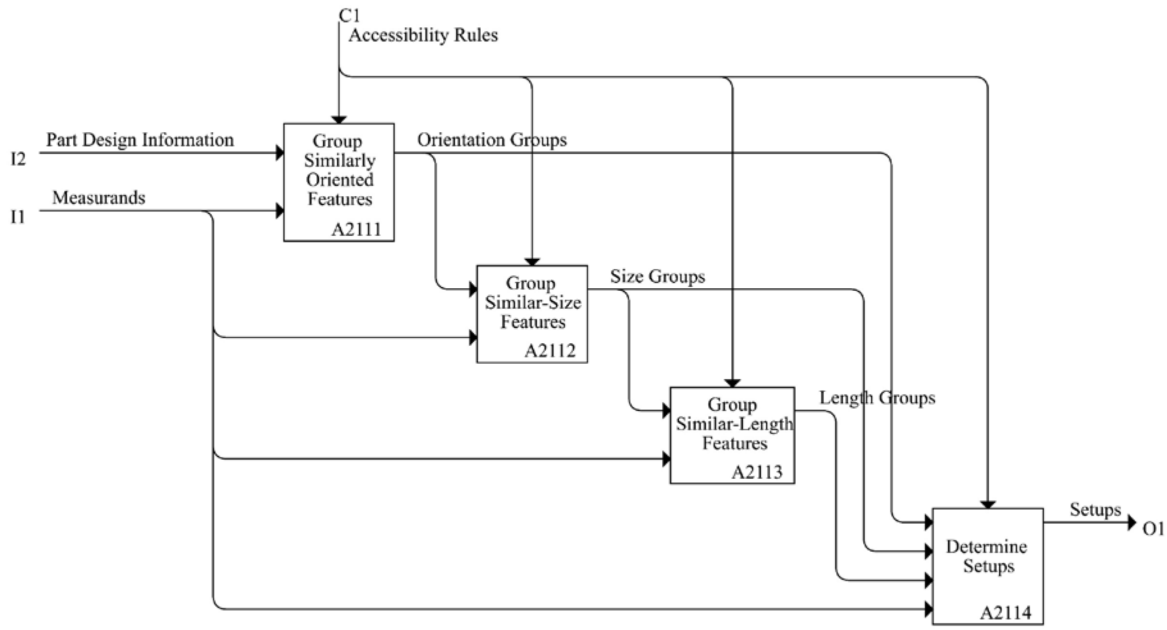

Figure 5 Determine accessibility and setups

Characteristics and tolerances are associated with Features. The output from A11 is Characteristics that need to be measured for verification against tolerances.

Activity A12 is to Determine Features and Boundaries. There are two types of features: ordinary features for part functions and datum features for establishing datums and datum systems. When determining features, measurement process planners must specify the feature boundaries within which the measurement instruments will be used to measure the feature. Sometimes, it is not possible to inspect 100 % of the feature due to other features interfering with instruments. The control parameter is Form Error Rules, i.e., rules to use to determine form errors of the features, such as drum shape of a shaft and three-lobes on a shaft. The output from this A12 is Features and Their Boundaries.

Activity A13 is to Determine Measurement Process Capability Requirements. The determined measurement process capability will be used to select measuring machines, devices, and gages in Activity A2. A control parameter is Accuracy Rules, which is part of Feature Rules. The output is Process Capability Requirements, which is a part of Measurands.

3.3 Activity to Select Measurement Resources

Activity A2 is decomposed into three subactivities: A21, A22, and A23. Figure 3 shows that decomposition.

Activity A21 is to Select a CMS. CMS stands for coordinate measurement system. CMS include a Coordinate Measuring Machine (CMM), probes and CMM probes adapter, and probe tips. Inputs are Measurands, Measurement Requirements, and Part Design Information. The control parameters are Manufacturing Processes, Measurement Rules, ASME B89, ISO GPS, and ASME Y14.5. The mechanism is the information about Available CMS, which is a part of Available Resources. The output is Selected CMS.

Activity A22 is to Select Other Measurement Devices to measure measurands. Another measurement device is one that is not a CMS or a gage and can be mechanical, optical, electrical, or ultrasonic. Examples are a laser scanner, ultrasound machine, and computed tomography scanner. The mechanism is Available Devices. The output is Selected Devices.

Activity A23 is to Select Gages. The mechanism is Available Gages. The output is Selected Gages. Selected Gages, Selected Devices, and Selected CMS comprise Selected Resources, which are the output of A2.

3.4 Activity to Select Coordinate Measurement System

Activity A21 can be decomposed into four subactivities: A211, A212, A 213, and A214. Figure 4 shows that decomposition.

Activity A211 is to Determine Accessibility and Setup. A211 will be further decomposed and will be discussed later. The inputs are Measurands and QIF Part Design. Inputs are Measurands and Design Information. The control is Accessibility Rules, which are used to determine feature accessibility by a CMS. The output is Setups that specifies the number of setups and what the setups are.

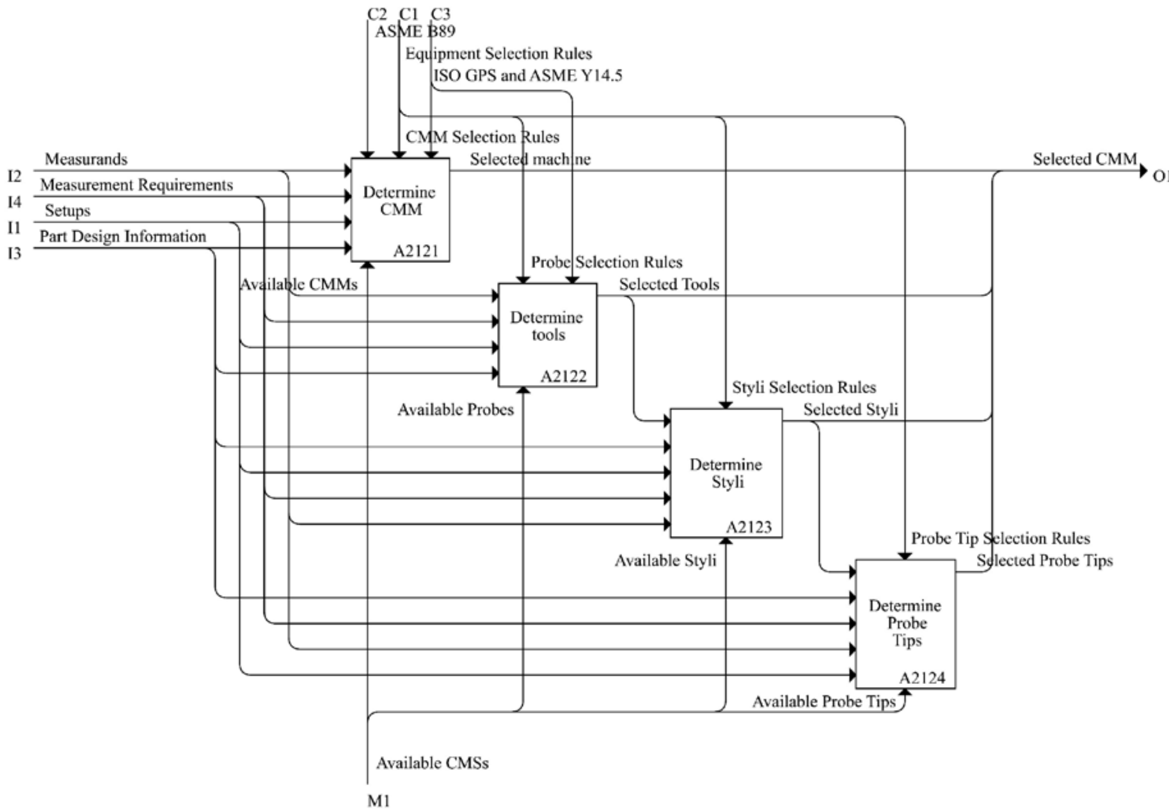

Figure 6 Select coordinate measuring machine

Activity A212 is to Select Coordinate Measuring Machine (CMM) and will be further decomposed. The controls are Equipment Selection Rules, ASME B89 standards, ISO GPS, and ASME 14.5. Equipment Selection Rules are part of Measurement Rules. The mechanism is Available CMS. The output is a Selected CMM.

Activity A213 is to Determine Probing Strategy. Probing strategy is how to sense features with a CMM probe. A213 will be further decomposed. Controls of A213 are Manufacturing Processes and Measurement Rules. The output is Probing Strategy.

Activity A214 is to Determine Fitting Algorithms. The activity is performed primarily based on Algorithm Selection Rules, as a control parameter, and all the inputs. Substitute Feature Requirements are selected fitting algorithms with fitting uncertainty. It takes inputs of Probing Strategy, Measurands, Part Design Information, and Measurement Requirements. The control is Algorithm Selection Rules, which are parts of the Measurement Rules. The output is Selected Fitting Algorithm. The Selected Fitting Algorithms, Probing Strategy, Selected CMM, and Setups comprise Selected CMS, which is the output of Activity A21.

3.5 Activity to Determine Accessibility and Setups

Activity A211 can be decomposed into four subactivities: A2111, A2112, A 2113, and A2114. Figure 5 shows that decomposition.

Activity A2111 is to Group Similarly Oriented Features. The purpose is for determine setups. Inputs are Part Design Information and Measurands. The control is Accessibility Rules. The output is Orientation Groups.

Activity A2112 is to Group Similar-Size Features. The size of an internal feature is used to determine sizes of probe tips to ensure that probes have enough maneuvering space in internal features, such as holes. Inputs are Oriented Groups and Measurands. The output is Size Groups.

Activity A2113 is to Group Similar-Length Features. The output is Length Group. The length of an internal feature is used to determine the length of styli used in CMM. Inputs are Size Groups and Measurands. The output is Length Group.

Activity A2114 is to Determine Setups. Inputs are Orientation Groups, Size Groups, and Length Groups. The output is Setups. The control is Setup Rules, which are part of Accessibility Rules.

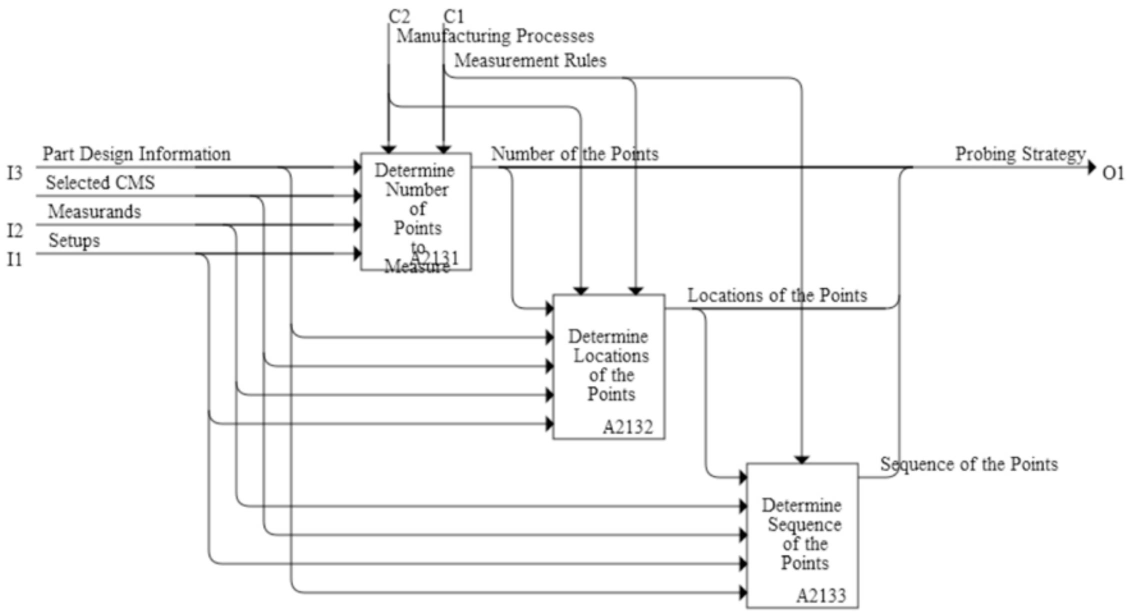

Figure 7 Determine probing strategy

3.6 Activity to Select Coordinate Measuring System

Activity A212 can be decomposed into four subactivities: A2121, A2122, A2123, and A2124. Figure 6 shows that decomposition.

Activity A2121 is to Determine CMM. Inputs are Measurands, Measurement Requirements, Setups, and Part Design Information. The output is Selected CMM. Controls are ASME B89, Equipment Selection Rules, ISO GPS, and ASME Y14.5. The Mechanism is Available CMSs.

Activity A2122 is to Determine Tools. Tools can be either integrated probe or detachable probe from an adapter to the CMM. The output is Selected Tools.

Activity A2123 is to Determine Styli. Inputs are Selected Tools, Measurands, Measurement Requirements, Setups, Part Design Information, and ASME Y14.5. The output is Selected Styli. The control is Styli Selection Rules, which are part of Equipment Selection Rules. The mechanism is Available Styli, which are part of Available CMSs.

Activity A2124 is to Determine Probe Tips. Inputs are Selected Styli, Measurands, Measurement Requirements, Setups, Part Design Information, and ASME Y14.5. The output is Selected Probe Tips. The control is Probe Tip Selection Rules, which are part of Equipment Selection Rules. The mechanism is Available Probe Tips.

3.7 Activity to Determine Probing Strategy

Activity A213 can be decomposed into three subactivities: A2131, A2132, and A2133. Figure 7 shows that decomposition.

Activity A2131 is to Determine Number of Points to Measure. Inputs are Part Design Information, ASME Y14.5, Selected CMS, Measurands, and Setups. Controls are the Measurement Rules and Manufacturing Processes. Rules for determine the number of points to measure are based on the four inputs and another input - Manufacturing Processes that make the part. The output is Number of the Points.

Activity A2132 is to Determine Locations of the Points. The locations are primarily influenced by the manufacturing processes, complexity of the workpiece, and tolerances. The output is Locations of the Points. A2133 is to Determine Sequence of the Points. The sequence is based on all the inputs, and the output is the Sequence of the Points.

4. CONCLUSIONS AND FUTURE WORK

An activity model of dimensional measurement planning has been developed using IDEF0 methodology. The activity model is uniquely developed for identifying activities, inputs, controls, mechanism, and outputs for determining characteristics/features to be measured. Also, activities of selecting measurement resources, including CMM, measurement devices, and gages are identified in the activity model. The main purpose of this identification is for developing rules for measurement resource selection to meet the industry need to cope with complexity of parts and available measurement equipment.

Future work is to develop measurement resources selection rules. It includes Boolean statements, and rule types.

ACKNOWLEDGEMENTS

This effort has been sponsored in part under the cooperative agreement No. 70NANB15H053 between NIST and The Catholic University of America. This material is

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