NISTIR 8102

End-to-end Demonstration of the Quality Information Framework (QIF) Standard at the International Manufacturing Technology Show (IMTS) 2014

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National Institute of
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Abstract

The "Silos of Quality" in manufacturing can be described as the proliferation of customized quality languages for different stages of production. This quality "Tower of Babel" results in excessive translations causing loss of information, reduction of features or capabilities, and/or translation errors. The Quality Information Framework (QIF) is a standard to solve the "Silos of Quality" problem in the discrete manufacturing industry. Because of the history with quality frameworks that suffered from a lack of adoption, a QIF demonstration was given at International Manufacturing Technology Show (IMTS) in 2014 to promote the fact that QIF is a suitable and excellent quality framework for manufacturers. This paper discusses modern production practices, and QIF basic concepts. It also details what QIF demonstrated at IMTS 2014.

Notation

AIAG	Automotive Industry Action Group
ANSI	American National Standards Institute
AP	Application Protocol
APQP	Advanced Product Quality Planning
ASQ	American Society for Quality
BoC	Bill of Characteristics
CAD	Computer-Aided Design
CMM	Coordinate Measuring Machine
DME	Dimensional Metrology Equipment
DMIS	Dimensional Measurement Interface Standard
DML	Dimensional Markup Language
DMSC	Dimensional Metrology Standards Consortium
FAI	First Article Inspection
GD&T	Geometric dimensioning and tolerancing
IMTS	International Manufacturing Technology Show
ISO	International Organization for Standardization
KPC	Key Product Characteristics
LOTAR	LOng Term Archiving and Retrieval
MBD	Model Based Definition
MBE	Model Based Enterprise
NIST	National Institute of Standards and Technology
PDF	Portable Document Format
PMI	Product and Manufacturing Information
PPAP	Production Part Approval Process
QMD	Quality Measurement Data
SPC	Statistical Process Control
STEP	Standard for the Exchange of Product model data
QIF	Quality Information Framework
XML	Extensible Markup Language
XSD	XML Schema Definition Language

1 Background

The Quality Information Framework (QIF) is a standard to solve the "Silos of Quality" problem in the discrete manufacturing industry. The "Silos of Quality" describes manufacturing elements using an individualized quality language but having difficulty in communicating quality information to other manufacturing facets. This problem can be attributed to the lack of a universal quality model and a standard representation, so that every quality manufacturing dialect requires translation into another representation resulting in information loss, lack of features or capabilities, or translation errors.

So why are "Silos of Quality" such a problem? Although factory-quality standards are available to manufacturers, acceptance has been negligible within the discrete parts industry. The problem is evident in previous standardization attempts – Dimensional Markup Language (DML) [1], Quality Measurement Data (QMD) [2], ISO 10303 Application Protocol (AP) 219 [3], etc. These standards have flaws such as incomplete models, narrowly-focused technology, poorly conceived design, or inadequacy in addressing fundamental manufacturers' quality requirements. QIF addresses these issues from the onset, bringing a comprehensive approach with a design that ensures thorough attention to manufacturers' quality requirements. The result is a seamless quality-integration standard – for the complete product-quality lifecycle. Plus, QIF is an open, royalty-free standard based on a de facto exchange standard – Extensible Markup Language (XML) [4] that makes use more affordable and acceptance easier.

Because it is a comprehensive quality standard, QIF enables seamless information exchange and sharing across the entire product lifecycle – inside or outside the enterprise. The measurement plans, measurement resources, etc., that are represented using QIF could be used by multiple sets of equipment or products in-house. It is desirable for all internal inspection functions to be interoperable among themselves. In addition, quality-data incompatibility affects the company's supply chain. QIF can ease bidirectional flow of quality information. Thus, the information generated by a quality process using QIF is readily useable by another quality process that adopts QIF. So, standardized formats mean quality exchange is possible between any two enterprises that adopt QIF.

The lack of acceptance of previous quality frameworks causes manufacturers to be wary of yet another quality approach. A QIF demonstration was given at IMTS in 2014 to convince skeptics that QIF is a suitable and excellent quality framework for manufacturers. We demonstrated an inspection application of QIF to a complete-measurement lifecycle. This QIF demonstration involved using a CAD design annotated with quality information, measurement equipment to inspect the produced parts to ensure that the parts are within the design specification, and reporting for statistical analysis of the quality results.

This paper focuses on the seamless integration of QIF knowledge throughout the production lifecycle. Section 2 describes modern manufacturing concepts with an emphasis on quality. Section 3 presents QIF and gives a brief background on some of its significant features. Section 4 presents the QIF demonstration given at IMTS 2014. Section 5 presents a discussion of the impact, benefits, and shortcomings of QIF at this stage of its deployment.

1 Quality Modeling

Two-dimensional product information has seen its capabilities far exceeded by three-dimensional modeling and analysis systems. Yet 2D drawings still retain a dominant role as contracting documentation. As manufacturing evolves, 3D-digital representations offer a better strategy since they supply more thorough and precise product information. In this 3D world, Product-and-Manufacturing Information (PMI) is emerging as a valuable development, since it includes not only digital design, but also facilitates a thorough 3D-annotation environment of quality information. PMI conveys design attributes necessary for manufacturing product components and assemblies, including geometric dimensions and tolerances, 3D annotation (text) and dimensions, surface finish, and material specifications. With PMI, the association of quality information, e.g., tolerances or surface finish, is expressly part of the product definition. It is the expression of quality-PMI information within the design phase that enables a universal representation of the product that can then be distributed and shared throughout the product-manufacturing lifecycle.

To better facilitate PMI, manufacturers are adopting the digital thread [5] concept to promote a model-based enterprise (MBE). The MBE goal is to streamline the flow of product information - interconnecting and sharing as much product information in the enterprise and supply chain as possible. It has the potential to save money by improving efficiency and accuracy and offering feedback and feedforward into the product lifecycle. In MBE, product information flows between all aspects of manufacture – design, fabrication, assembly, and inspection. Feedforward refers to the use of information for adaptive control of downstream systems in the product lifecycle, i.e. or "later" in the lifecycle. For example, feedforward PMI could incorporate design information during fabrication of a product. Feedback refers to the use of information for adaptive control of upstream systems in the product lifecycle, i.e. or "earlier" in the lifecycle. For example, feedback could use fabrication information upstream in a revised design of a product to simplify manufacture.

Although the QIF, PMI, and MBE approach has significant advantages in efficacy and agility, a large portion of the manufacturing industry still uses drawing-based practices. For inspection, a human-based procedure would have shop-floor-quality personnel reviewing the inspection reports to determine how the products compared to the functional requirements. As such, often, quality engineers get hard copy Portable Document Format (PDF) reports on the quality inspections, or else receive data produced from one of many different coordinate-measuring machines (CMM) that would have to be translated and/or interpreted before being represented in the reports.

The desirable situation newly enabled by QIF is to be able to take the digital CAD with associated PMI, provide manufacturers with measurement plans, and receive from the manufacturers the measurement results in a standardized format. Since the quality reports can represent a large amount of data from various inspection machines, the standard format allows easier integration. With easier integration, it is now possible to have detailed and comparative analysis, thorough report generation, and reduction of errors previously caused by data transformations. In the foreseeable future, it will be desirable to use QIF results for the remediation of failures. This will require a deeper understanding of the correlation of the QIF results and production processes.

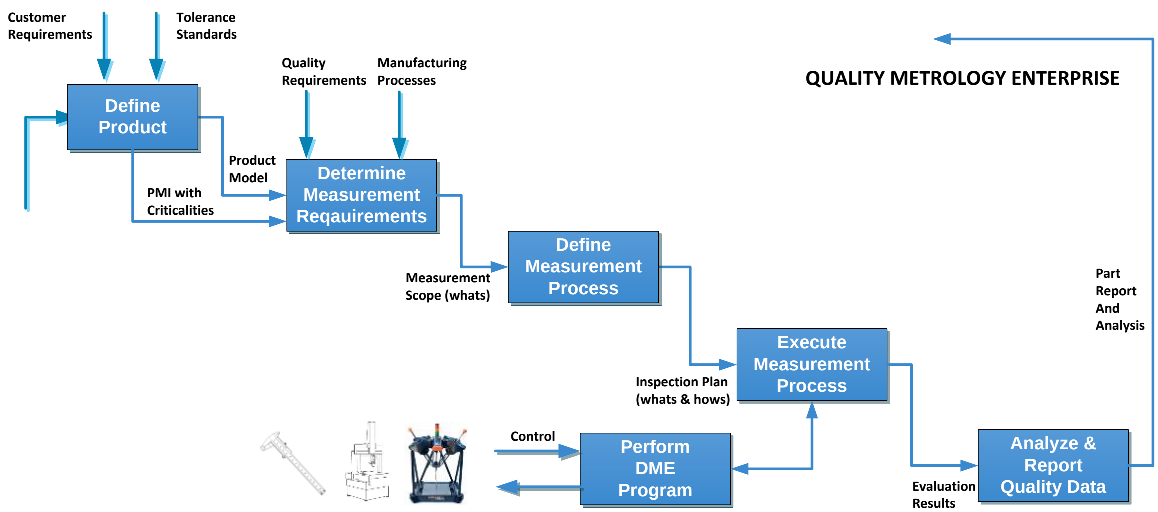

Figure 1: Quality Process

Product design has advanced from drawing based to model based. So too, the quality process has evolved. Figure 1 shows the basic steps in a quality process that involves inspection and measurement resources. These steps include:

- Define product – take in functional requirements of the product, and represent quality using tolerance standards
- Determine measurement requirements – decide what to measure: part features/characteristics based on product-quality requirements and manufacturing processes available to make the product;
- Define measurement – assign resources and use metrology knowledge (e.g., inspection rules) to meet measurement-accuracy constraints;
- Execute the measurement on appropriate dimensional-metrology equipment (DME);
- Analyze quality data and report results with the goal of improvement.

2 Quality Information Framework Standard Architecture

Applying standards is a common way of achieving interoperability and integration. QIF Version 2.0 is an approved ANSI standard [6]. Quality practitioners who use QIF can benefit from its standardized model format, which enables:

- Eliminating human involvement through computerized information exchange;

- Minimizing quality information translation errors;
- Supporting quality requirements related to the part manufacture or part procurement, but excluding quality requirements related to buildings, equipment, distribution, handling, etc.;
- Having different computer systems communicate quality information.

QIF satisfies numerous customer-use-case requirements. For example:

1. QIF covers all of ASME Y14.5-1994 Geometric dimensioning and tolerancing (GD&T) functionality and some of ASME Y14.5-2009 excluding much of the composite extensions [7];
2. QIF covers all of First-Article-Inspection Reporting AS9102b; [8]
3. QIF covers parts of ISO 1101.3 standard where GD&T overlaps with the ASME Y14.5 standard, but there are differences between the ISO and ASME standards; [9]

The QIF standard specifies a set of information models in the form of XML schemas [10]. QIF enforces standardization by requiring that all the XML instance files conform to the QIF schemas. Thus, every XML instance file can be parsed and validated using the QIF XML schema files. In addition, QIF contains code to ensure that XML references don't refer to missing information, or don't refer to wrong types of data. QIF is well documented; readers are referred to [11] for a complete overview.

Figure 2 shows the QIF architecture. At the core of the QIF architecture is the reusable QIF Library that contains definitions and components that are referenced by the application areas. This QIF Library contains multiple sets of basic information models, such as primitive types for PMI, primitive types for product description, geometry for product descriptions, topology for product description, traceability information, and units. Around the QIF library core, Figure 2 shows the six QIF application area information models: Model-Based Definition (MBD) (QIFProduct), Plans, Resources, Rules, Results, and Statistics. The "QIF Execution" model is, in the current version of QIF, a placeholder for future standardization and is now handled by the Dimensional Measurement Interface Standard (DMIS) standard [12]. The order of generation of QIF data generally proceeds clockwise around the diagram, beginning with QIF MBD and ending with QIF Statistics. Users of QIF are not required to implement the entire model or to use a particular sequence of activities.

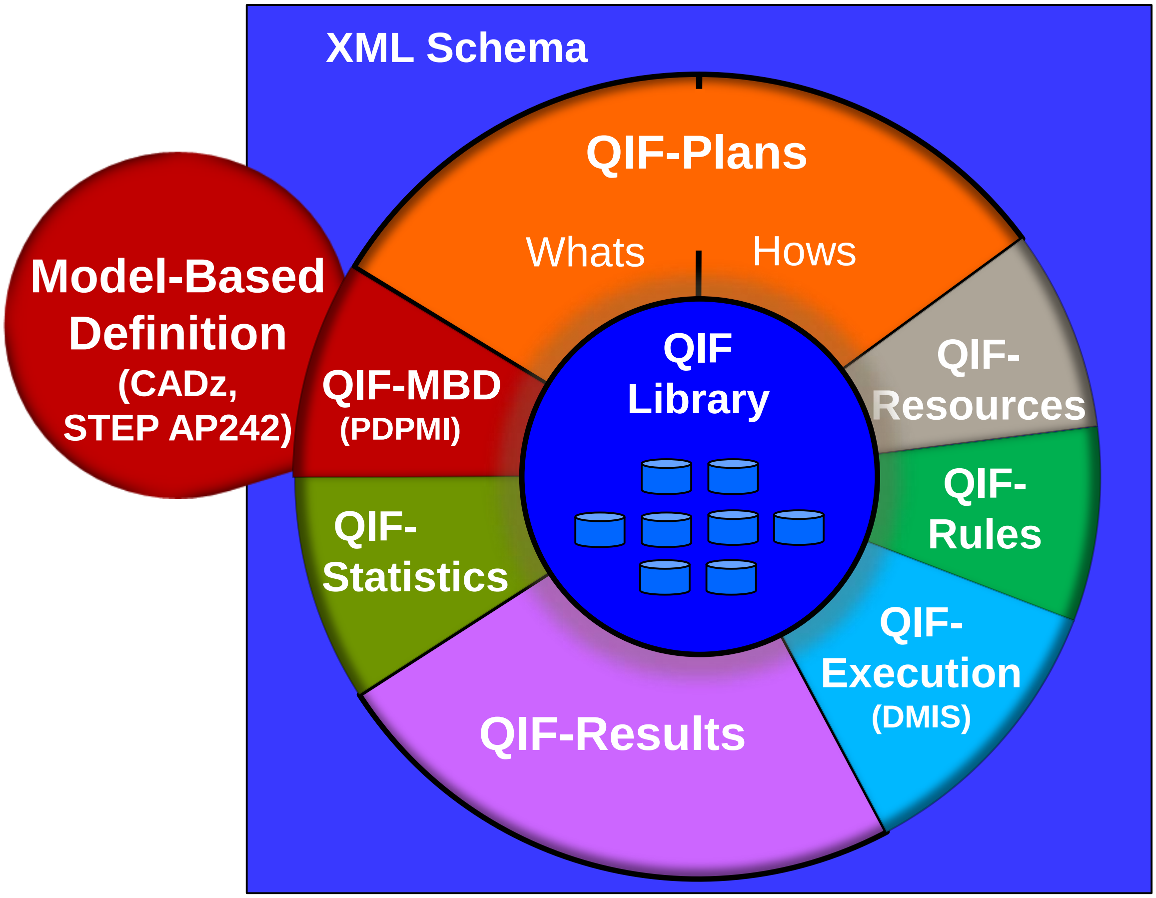

Figure 2: QIF Lifesaver Architecture: Library and Application

QIF assigns identifiers whenever schema instances are created for any measurement object that is to be referenced (feature, characteristic, rule, resource, etc.). When related information is in a single file, it is either nested hierarchically or connected using identifiers (ids) that are local to the file. When related information is in separate files, it is connected using a combination of local ids and QIF Persistent Identifiers (QPIds), which are universally unique. [13]

QIF also includes manufacturing and metrology traceability. Traceability items include:

- The product/part model: the CAD system that was used to create it, the designer, the version, etc.
- The quality enterprise: performing organization, product/part references such as order number and its assembly path (AsmPath, see QIF v. 2.0, MBD section 7.4).
- Inspection scope: detail or assembly as used in AS9102A first article inspection,
- Inspection mode: 100 %, full/fail, partial/fail, or to follow one of the industry practices such as advanced product quality planning (APQP), key product

characteristics (KPC)[1] [14], and production part approval process (PPAP) that industry groups such as the Automotive Industry Action Group (AIAG) and the American Society for Quality (ASQ) use [14] [15].

- Adopted standard: such as ASME-Y14.5 [7].
- Additional information that helps traceability: e.g., security classification (unclassified, for official use only, trademarked, trade secret, patented, EU Restricted, etc.).

3 IMTS QIF Interoperability Demonstration

A QIF demonstration was given at the 2014 International Manufacturing Technology Show (IMTS). IMTS is the largest manufacturing technology show in North America. More than 2,000 companies exhibit and over 100,000 individuals visit IMTS, which is held every even-numbered year in Chicago, Illinois, USA. At IMTS 2014, an end-to-end QIF demonstration was given to show how interoperability in quality processes could be successfully achieved with QIF. A video presentation of the IMTS demonstration hosted by Ray Admire of Lockheed Martin is available and titled, "IMTS 2014 - DMSC Demonstrates New QIF 2.0". [16]

At IMTS, the integrated demonstration involved 13 companies facilitated by National Institute of Standards and Technology (NIST) and Dimensional Metrology Standards Consortium (DMSC). The demonstration workflow is shown in Figure 3. NIST is not a quality vendor, but offered services to assist in the demonstration planning and logistics. DMSC is the umbrella organization that sponsors QIF and acquired IMTS booth space.

[1] There are additional, similar practices such as key process parameters (KPPs) and critical-to-quality items (CTQs) as the referenced society describes.

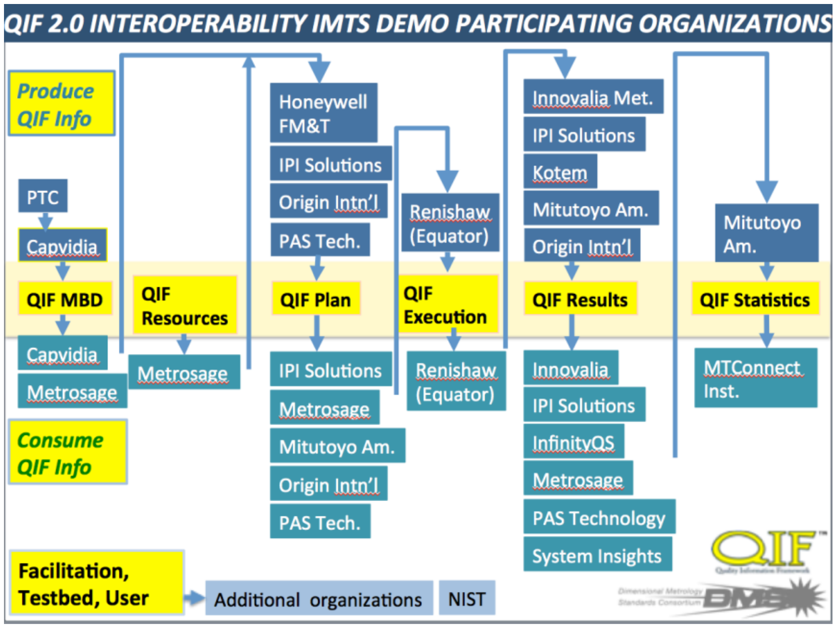

Figure 3: IMTS 2014 QIF Workflow

The quality-measuring device was the Renishaw Equator. The Renishaw Equator is a low-cost and high-speed comparative gauge for inspection of manufactured parts. Figure 4 shows the Renishaw Equator used for measurement at IMTS 2014. All other commercial products were software applications even though some of the vendors have measurement devices.

Figure 4 Renishaw Equator

Figure 5 shows the widget selected for the IMTS demonstration. The “QIF Widget” was chosen for the IMTS demo because the design features that it contains are representative of a wide range of industry applications. With this part, the IMTS demo participants were able to simulate the types of features, datums, datum-reference frames, and tolerances that end users are accustomed to working with.

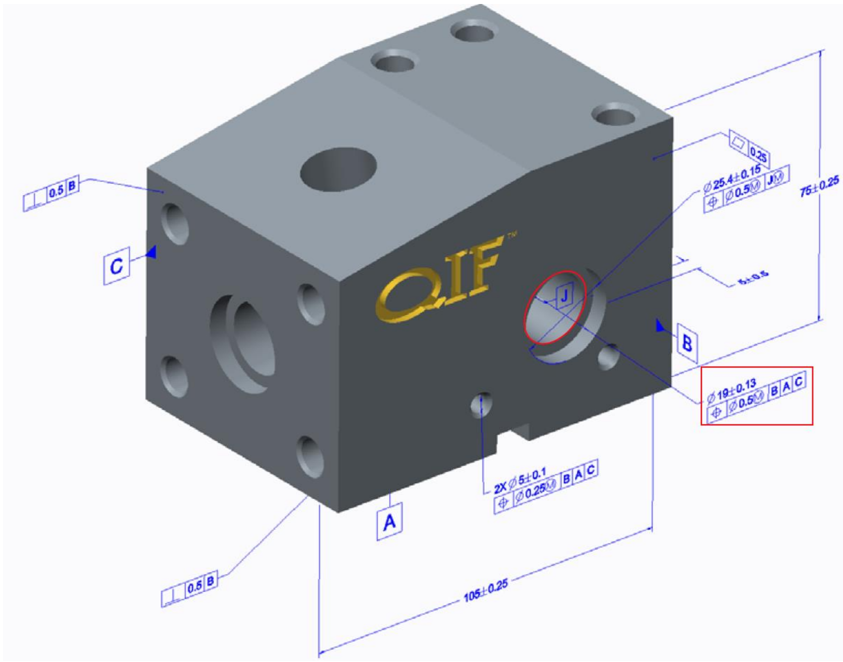

Figure 5: IMTS 2014 QIF Demonstration Part

Outside the current scope of QIF is CAD/PMI, which produces a Model-based definition (MBD). MBD uses a digital-data format to define a product or part, in terms of geometry and topology. The topology defines boundaries for the geometrical objects and includes topological items such as body, shell, face, edge, and vertex for modeling parts or products. For manufacturing purposes (fabrication or quality), the MBD definition must be rich enough to contain all the required information, including part geometry and quality-functional requirements (e.g., GD&T and surface finish).

A commercial CAD system produced by PTC (formerly Parametric Technology Corporation) was used to create a MBD for the widget. The MBD contained geometric features and tolerances, and PMI; similar to that specified in ASME14.41 [17] and STEP (Product data representation and exchange) [18].

3.1 MBD into QIF MBD

A quality design using a proprietary format, even one with MBD, would have resulted in extra work for the quality engineer, as she/he would need to translate this format to be compatible with all the quality-inspection steps. This would less of a problem if the CAD system output MBD into a QIF format. Even then, MBD to QIF format depends on some simplifying assumptions for success. For IMTS 2014, the MBD was assumed to exhibit the following properties:

1) PMI exists and the PMI includes the quality and tolerance information that metrology needs;
2) Such PMI quality information is represented as semantic PMI, that is, in a standard digital format, is software interpretable, and is related to feature(s);
3) Mapping of MBD design features into QIF inspection features is limited to basic manufactured features (e.g., simple holes, surfaces).
4) The translated QIF inspection feature(s) retain 100 % of the MBD PMI intent.

At IMTS, Capvidia [19] demonstrated MBDVidia for PTC Creo, which converts native PTC Creo MBD models into QIF MBD retaining all semantic PMI, notes, metadata, and saved views. MBDVidia for PTC Creo also automatically recognizes and generates metrological features and characteristics so that several downstream processes can use the resulting QIF model. A metrological feature is a physical portion of a part such as a surface, pin, hole, or slot or its representation on drawings, in models, or in digital data files [7]. A metrological characteristic is a control placed on an element of a feature such as its size, location or form, which may be a specification limit, a nominal with tolerance, a feature control frame, or some other numerical or non-numerical control [11].

Similarly at IMTS, the PAS Technology Company demonstrated its "Inspection Lifecycle Management (ILM) Suite" product to extract information from a 2D print of a part definition (a large portion of the industry still uses this method) and convert printed matter into a QIF plan.

3.2 QIF Plan

Given a MBD in QIF format, Honeywell Federal Manufacturing and Technologies (FM&T) developed and used a model-based application (FBTOL) [20] that performs a semantic tolerance analysis on piece-part models. For the IMTS demonstration, FBTOL performed the "Define Measurement Process" work activity by reading a model-based definition with PMI (i.e., QIF MBD), performing a quick tolerance-definition check, and then producing a high-level QIF Plan representing an inspection scope. This scope contains a list of the characteristics with measurement elements that need verification. This list is commonly known as the Bill of Characteristics (BoC) for manufacturing-quality consumption. The FBTOL tool checks the correctness of the semantics of the tolerance specification. FBTOL generally needs to achieve near a 100 % correct score for a measurement plan to be confidently created.

Such a BoC plan would include all the main plan elements, such as human-readable designators and universally unique ID's, traceability back to part features, datum definitions, datum-reference frames, tolerances, and even other product information (e.g., grain sizes and colors). A graphical representation of the resulting BoC is shown in Figure 6.

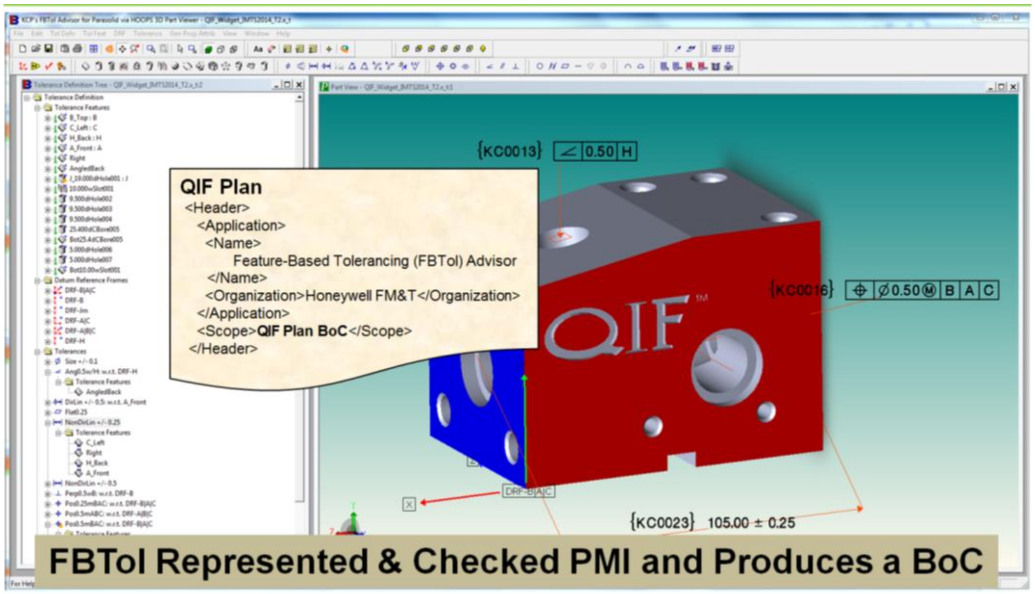

Figure 6 FBTOL graphic representation of the resulting BoC

Metrosage demonstrated its Pundit CMM simulation software at IMTS. Metrosage's simulation software requires part geometry and GD&T—and the semantic link between the two of them. As mentioned, applying GD&T manually to a model can be protracted and subject to human transcription and interpretation errors. For this reason, data standards that support semantic PMI, such as QIF, are quickly becoming a leading format for transmitting fully semantic GD&T information. Metrosage's Pundit CMM is built upon QIF and supports the QIF MBD format as a standard feature.

3.3 Executing QIF Plan and Generating QIF Results

The current version of QIF, 2.0, does not include an inspection-execution component. An adjunct DMSC metrology standard, the DMIS-programming standard may be used as the inspection language for executing the measurement plan. AT IMTS, Origin International Corp. [21] demonstrated an implementation of the DMIS code using the Renishaw Equator, and measured a cylinder identified in the BoC.

Origin recorded the quality-measurement results in QIF after the execution of the detailed QIF Plan. The QIF measurement results were matched with the respective features using the QPIds in the demonstration. QPIds are essential within QIF. For example, when Renishaw's Equator product finished executing a measurement plan, Origin International's software matched QPId with the part and machine information to produce specific QIFResults files, that were later used by multiple demonstration participants.

The Mitutoyo America Corporation MeasurLink tool [22] consumes a QIF plan and displays it onscreen during execution or simulation. MeasurLink combines real-time on-line data collection with real-time statistical-process-control (SPC) charts and analysis for operators, and with real-time quality control / supervisor reports and alerts. Since MeasurLink is designed for integrated networks, comprehensive quality information sharing with QIF is possible.

Metrosage LLC demonstrated its Pundit [23] tool, which uses Monte-Carlo-simulation techniques to calculate task-specific measurement uncertainty, for example, the uncertainty for the measurement of a diameter tolerance of a feature. Metrosage uncertainty simulation software used QIF as the source for its measurement data. Figure 7 illustrates the information requirements for the tool to run an uncertainty simulation. All of these inputs are supported by QIF. Complex feature geometry can be taken from QIF MBD data, while prismatic geometry can also be taken from the feature section of simple QIF Results or QIF Plans files. The GD&T for the geometry is defined within the QIF Library. Sampling patterns can be taken either from a QIF Plans instance file or from a QIF Results instance file. A manufacturing-error signature of previously manufactured parts can be calculated by looking at QIF Results data. The measurement systems can be implemented using the QIF Resources model that contains all the required fields needed for the uncertainty simulation. Without QIF, these data sources are typically defined in different formats and require special processing before being entered into Pundit.

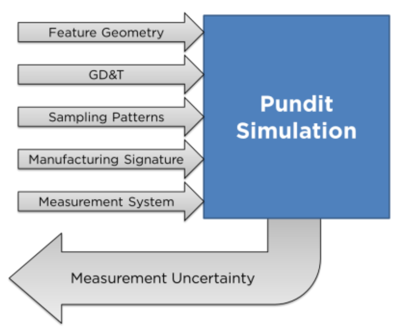

Figure 7: Measurement uncertainty simulation

3.4 QIFResults

At IMTS, several companies demonstrated products that used QIF results (InfinityQS, Innovalia Metrology, IPI Solutions Ltd., Origin International Inc., and Kotem Hungary Ltd.). These results have the benefit of being free from possible human-interpretation errors, accurately retaining the design intent, and enabling automatic-quality processes.

1. InfinityQS International [24] consumes QIF Results, which could be from CMM or other measurement systems. QIF Results were combined to produce graphs and to produce different types of information such as statistics, alarms, histograms, capability reports, and respective indications on the part graphics.
2. Innovalia Metrology [25] demonstrated importing QIF Results from various measurement resources, analyzing QIF Results, and then generating reports.
3. IPI Solutions Ltd. [26] demonstrated Visual-IPI software that generated FAI or PPAP reports, commonly required by quality engineers. In the demonstration, Visual-IPI read and interpreted a 2D PDF drawing (but could also have accepted a 3D QIF MBD) to identify all the characteristics that are then used in a FAI or PPAP template. QIF files were then read for results to populate the report template. Any errors that occurred, such as out-of-tolerance or missing data, could be identified in the report. The benefit of using QIF is also evident in that the software is no longer required to convert all individual quality data formats, thus avoiding the “Silos of Quality” problem discussed earlier.
4. Origin International Inc. [21] demonstrated loading results for graphic reporting and analysis. Figure 8 shows a graphical screenshot of the Origin report and analysis from the IMTS demonstration.

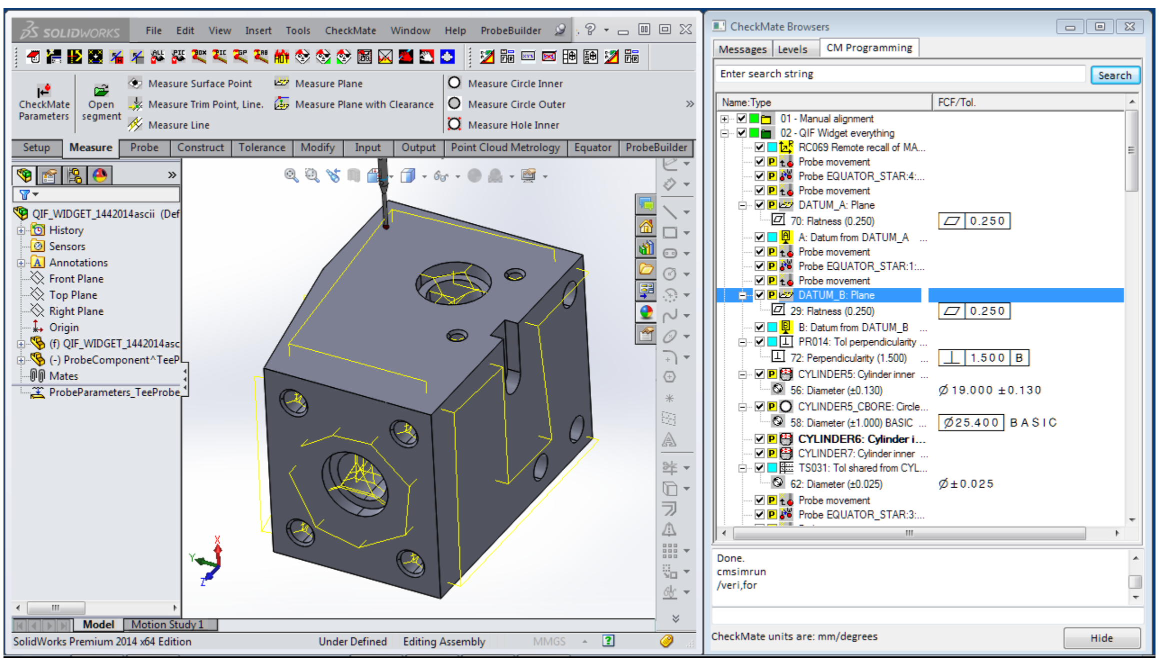

Figure 8 Origin International Graphical User Interface for Reporting and Analysis

5. Finally, Kotem Hungary Ltd. [27] demonstrated its SmartProfile tool, which involved reading QIF Results along with QIF MBD and other related information and analyzed the resulting part. Again the “Silos of Quality” problem was avoided as the SmartProfile tool only needed to understand one data format, QIF. Kotem’s customers would benefit from the company’s ability to apply the

PMI onto the relevant features without extra effort, thus avoiding potential errors as a result of translation of an already entered proprietary electronic representation.

3.5 QIFStatistics

At IMTS, Mitutoyo America demonstrated its MeasurLink SPC data-management tool [22] consuming a plan (derived from the MBD) and mapping it to a measurement device for execution and statistical processing. Included in the SPC-graphical analyses were statistical properties such as Cp and Cpk for capability and Pp and Ppk for process capability. [28] [29]

3.6 QIFResults collection for analysis

At IMTS, System Insights demonstrated its Vimana [30] tool that leveraged MTConnect [31] to collect shop-floor-real-time data and analyzed the data for metrics such as productivity, downtime, tool wear, deviations from plan, and cycle time. MTConnect is able to provide QIF data as an "asset". [32] This quality integration expands the flow of production data into a complete spectrum accessible by any system using the MTConnect standard.

4 Discussion

QIF model-based metrology offers significant advantages over the traditional practices. One benefit is that QIF can incorporate MBD as a digital thread throughout the product lifecycle. Another benefit is that QIF facilitates a software component/library approach so users or adopters don't need to implement the entire QIF functionality. In this case, downstream-quality tools can import QIF data, and modify QIF data, without concern for which upstream tool generated the data. Standardization also means opening hidden information that was unavailable and inaccessible otherwise.

From the perspective of smart manufacturing, QIF should enable interaction among all the production-quality activities. Interim-quality results could be provided to other interested processes. QIF-enabled quality-data accessibility furthers the trend toward digital manufacturing and Industry 4.0. [33] Inspection results should be easier to evaluate and customize, so improvements can be first identified within the inspection process and then applied to manufacturing processes. This pervasive quality interaction would improve machining processes, which in turn would improve product quality. On an even broader scale, the quality results could be fed back to the product-design stage for improvement of the product design/definition.

Currently QIF is in an adoption stage. Early adopters and their vendors are using QIF to standardize on a comprehensive quality standard throughout their enterprise. The "Silos of Quality” problem undermining an enterprise’s quest for excellence is a major driver in this QIF deployment. As more and more implementations arise, the QIF standard will evolve and new requirements and challenges will be addressed. In fact, a QIF version 2.1 is underway. QIF 2.1 covers significant LOng Term Archiving and Retrieval (LOTAR) requirements with recent additions to QIF made for this requirement. [34]

Disclaimer

Commercial equipment and software, many of which are either registered or trademarked, are identified in order to adequately specify certain procedures. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

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