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1 An Integrated Data Model for Quality Information Exchange in Manufacturing Systems

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Abstract. Quality measurement is an integrated part of modern manufacturing systems. As the manufacturing industry has entered a digital and virtual era, information technology has become increasingly important for both machining and measurement systems. Effective information sharing and exchange among computer systems throughout a product's life cycle has been a critical issue. The quality measurement industry and standards organizations have developed several successful standard data models to enable standardized data. However, these standards have very restricted focus. From late 2010, the Quality Information Framework (QIF) project was initiated by the Dimensional Metrology Standards Consortium (DMSC) with the support of major North American quality measurement industries. This project aims to develop an integrated Extensible Modeling Language (XML) data model for the entire quality measurement chain. It consists of five application area schemas and a QIF library with nine supporting schemas. This paper introduces the scope and data model design of QIF. A pilot test project using the recently completed QMResults schema for the exchange of inspection result data is also presented.

Keywords: Quality Information Framework (QIF), manufacturing quality systems, information modeling, data model, XML schema, measurement features, characteristics, ASME Y14.5

1.1 Introduction

In the past two decades, the manufacturing industry has undergone drastic changes: digitization of manufacturing process chain, globalizing supply chain, fast technology development, and escalating complexity of products. For major manufactureres, such as airplane manufacturers, automobile manufacturers, etc., the technology bottleneck is shifting towards manufacturing systems integration and enterprise systems integration. The reason for this situation is that hardware and software systems generally process input and output data in their own data formats. A typical manufacturing chain often consists of (from upstream to downstream) Computer-Aided Design (CAD) software, Computer-Aided Manufacturing (CAM) software, Computer-Aided Inspection Planning (CAIP) software, and Statistical Process Control (SPC) software. The information can not flow directly from upstream to downstream without data translation. Translation is not only time and money consuming but also results in loss of integrity of information. Furthermore, the information exchange between CAD systems from different vendors also needs data translation. There are many research efforts in standardizing data exchange within manufacturing systems. This paper will present a new effort aiming to develop a consolidated data model library for the exchange of quality data within manufacturing systems. This effort is called the Quality Information Framework. A primary benefit of this research is to reduce resources needed for systems integration in all manufacurting industries that implement dimensional metrology systems. In 2006, the automotive industry alone reported that costs due to translation of measurement data between manufacturing systems amounted to over $600 million annually [1]. Moreover, adopting QIF will facilitate commercially available components to be interoperable allowing users to buy the products that suit their individual business models.

This paper is organized in the following manner. Section 1.2 will give a brief introduction of a typical manufacturing quality system. Section 1.3 will present the QIF data model library developed in this research effort. Three case studies that were carried out to test the data model will be discussed in Section 1.4. Conclusions are drawn in Section 1.5.

1.2 Flow of Information in Manufacturing Quality Systems

Manufacturing quality systems comprise the software and hardware used for quality control in a manufacturing process. Quality control is intertwined with machining activities in a manufacturing process. As shown in Fig. 1.1, there are four main elements in a typical manufacturing quality system: measurement planning, inspection programming, measurement execution, and quality results analysis and reporting [2]. The solid lines in Fig. 1.1 represent the common information flow in typical manufacturing quality system; while the dotted lines represent alternative information exchange. Product definition information is the highest level upstream information flowing into any manufacturing quality system. It is the combined information of product design information (generated through CAD software) and multiple quality management requirements such as Product Lifecycle Management (PLM), First Article Inspection (FAI) requirements, Enterprise Resource Planning (ERP) information, etc.

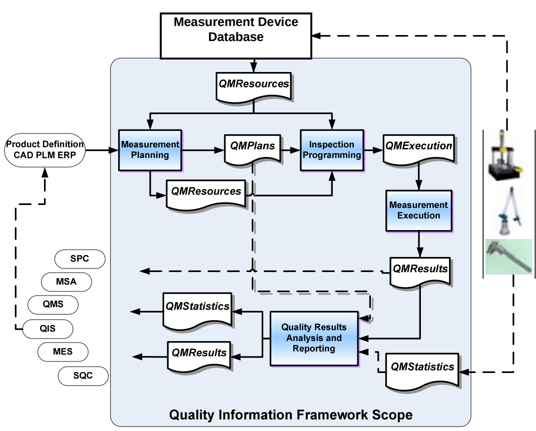


Fig. 1.1. The scope of QIF

The measurement planning activity receives all the information mentioned above and takes into consideration of the availability of quality measurement resources to generate measurement plans. Descriptions of all inspection resources in a facility, as well as resources assigned to specific plans are formated according to the *QMResources* data model. High-level plans, formatted according to the *QMPlans* data model, identify the measurement features, their characteristics, and the measuring sequence. The function of the inspection programming activity is to generate the machine-level measurement plan for execution based on available measurement devices. Low-level plans, formatted according to the *QMExecution* data model, provide detailed measurement operation information (i.e. probing points, scanning routes, etc.). The function of the inspection programming activity is to generate the machine-level measurement plan for execution based on available measurement devices. Most coordinate measuring machines (CMMs) require the execution commands to follow specific proprietary format for their controllers. This process is carried out by the measurement execution activity, whose responsibility is to interpret machine-level measurement plans, give equipment level commands to specific CMM control units, collect point data, fit features to data, and output feature and characteristic data formatted according to the *QMResults* data model.

Once the machine-level measurement plans are executed, the measurement data, either raw data or pre-processed data, is collected, reported, and analysed. The collection and the analysis of multiple part inspections are formatted according to the *QMStatistics* data model. The purpose of quality control is not just to judge whether a product meets the functional requirements of the design after it is manufactured. The data gathered through quality control (both in-process and post-process) can also be used to assess the performance of the machine, to judge the quality and the efficiency of the machining process plan, and to trace any unexpected anomalies during the manufacturing process. Through analyzing measurements data, statistic process control can provide feedback to upstream processes, such as CAD design, statistical quality control (SQC), etc., to improve the production of future products.

1.3 QIF Scope and Schemas

There are multiple international standards effort trying to develop suitable data model to overcome the interoperability barrier in manufacturing quality systems. Reviews of these international standards efforts can be found in references [2-6]. Each effort focuses on a narrow slice of the overall manufacturing quality system. Most of them developed independent data models, which often overlap with other models, contributing to interoperability problems. The QIF effort was initiated by the DMSC [7] aiming to overview the existing standard data models in manufacturing quality systems to develop a consolidated data model to cover the entire manufacturing quality chain. The contents of the QIF data model was designed to encode all information in ANSI/ASME Y14.5 2009 [8] and the Dimensional Measuring Interface Standard (DMIS) 5.2 [9]. The scope of QIF covers the five interfaces shown in Fig. 1.1.

1.3.1 QIF Schemas

The current release of QIF Version 0.9, has the QMResults application area schema and nine supporting schemas complete and released for beta testing. The QMPlans schema is in draft shape and the remaining three schemas have been planned to be developed in the near future.

The supporting data model schemas, collectively called the QIF Library, are named as following:

- **CharacteristicTypes** - defines quality requirement information, including geometric dimensioning and tolerancing (GD&T) tolerance, attribute tolerance (i.e., Go/No-go gaging requirements), and user defined requirements.
- **FeatureTypes** - defines all 28 types of measurement features found in DMIS 5.2.
- **ConstructedFeatureTypes** - defines methods of constructing measurement features.
- **Units** - defines units for values of angle, area, force, length, mass, pressure, signed length, speed, temperature, and time.
- **MeasurementDevices** - defines the basic information regarding measurement devices such as probe accuracy, stylus length, touch-triggering force, etc.
- **Traceability** - defines traceability information within the manufacturing quality system and with the machining process, such as part serial number, machine tool number, process id, etc.
- **Transforms** - defines coordinate systems transformation information.
- **PrimitiveTypes -** defines primitive common information that is used by other application area schemas but is not covered in the above supporting schemas, such as degree of freedom, notes, measure point, etc.
- **QIFTypes** - defines non primitive common information used by application area schemas but not covered by the above supporting schemas, such as file type, model entity, software type, etc.

One of the five application area schemas, QMResults, has been built and is believed to be technically complete for the reporting purposes it was built to serve. It is expected that testing and debugging will add only minor items related to those purposes. Testing the QMResults schema began in October 2011, when sample test files were first built. A second application area schema, QMPlans, has been drafted but, as of February 2012, is not technically complete.

1.3.2 Semantic Connecting Types Using Identifiers

In QIF each characteristic and feature is defined using four ***aspects***: definition, nominal, actual, and instance. These have identifiers and are connected by references to the identifiers. Notes may be attached to any of the four aspects. Take features as an example:

- A **feature definition** includes information that is independent of the position of the feature - the diameter of a circle, for example. A single definition can be referenced by many nominal features. Only nominal features reference feature definitions.
- A **feature nominal** defines a nominal feature by referencing a feature definition and providing position information - the center of a circle and the normal to the plane of the circle, for example.
- A **feature actual** defines an actual feature that has been measured or constructed. A feature actual may optionally refer to a feature nominal and is expected to do so if there is a nominal feature. There may not be a nominal feature if the actual feature is built during a reverse engineering process.
- A **feature instance** represents an instance of a feature at any stage of the metrology process - before or after a feature has been measured. The feature instance must reference a nominal feature or an actual feature. If an actual feature is referenced, the corresponding nominal feature (if there is one) may be found through the actual feature. If a feature is measured several times, it is expected that a feature instance will be defined for each measurement and will have a different actual feature for each measurement.

In XML data files, relationships between the four aspects are expressed using strongly typed links, whose types are related to the data elements they are linking. This use of typed links, or references, will allow standard XML data file validation rules to enforce integrity of the relationships. A more technically detailed discussion of this technique can be found in the design and usage guide of QIF, which will be published soon by NIST.

1.3.3 QIF Validation to ANSI/ASME Y14.5 2009

The CharacteristicTypes schema represents the entire GD&T requirements defined in ANSI/ASME Y14.5 1994 standard. In order to make QIF compatible with the newly published 2009 version, a validation effort was carried out to update CharacteristicTypes with all the new GD&T requirements. Table 1.1. lists some of the new items defined in the 2009 version. Some of the new items are accompanied with new symbols. This validation process is still ongoing.

1.4 Case Studies for Validating QIF

In September 2011, the QMResults schema Version 0.9 was released by the QIF QMResults working group. Since then, a series of validation tests have been carried out to evaluate correctness and completeness of the specification. The first step of the validation was to create QMResults data files containing simulated measurement results for sample parts. The validation requirement is that the data files contain all measurements described by part drawings, and that the XML data files be correct according to the QMResults schema. Part drawings shown in Fig. 1.2 are:

1) a CMM calibration master ball
2) Advanced Numerical Control (ANC) 101 example part
3) Sheet metal scanning measurement example part.

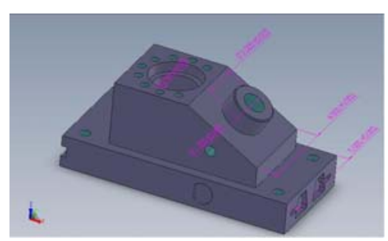
1.5 Conclusions

Based on the development of QIF to date, the DMSC believes that a complete set of specifications will facilitate simple integration of commercial software solutions for manufacturing quality systems. Exchange of quality data in standard formats is judged to be a good solution to achieving interoperability of multi-vendor software components. Benefits accrued to manufacturers should include flexibility in configuring quality systems and in choosing commercial components, and effortless and accurate flow of data within factory walls as well as with contractors and suppliers. In order to facilitate and encourage software applications that manipulate QIF formated data, DMSC proposes, in the near future, to create software libraries that write data into QMResults XML files (serialization), and/or read data from QMResults XML files (deserialization). This software development will be an open source, public domain project so members of the manufacturing quality community can suggest improvements or improve the code for the benefit of all users.

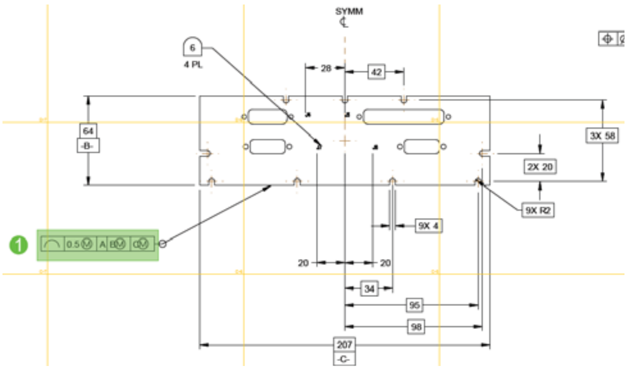
Table 1.1. New GD&T information in ASME Y14.5 2009

New Items	**Symbols/ Indicator**
All over	
Movable datum targets	A1
Unequally disposed profile	Ⓤ
Independency	Ⓘ
Continuous feature	⟨CF⟩
Datum translation	▷
Maximum Material Boundary (MMB)	Ⓜ
Least Material Boundary (LMB)	Ⓛ
Regardless of Material Boundary (RMB)	N/A
Nonmandatory (MFG DATA)	N/A
Datum feature simulator	[ ] ,BASIC or BSC
Explicit degrees of freedom for datum reference frames	[u,v,w,x,y,z]
More than two tier composite position control frames	N/A
More than two tier composite profile feature control frames	N/A

a) a CMM calibration master ball



b) ANC101 example part



c) Sheet metal scanning measurement example

Fig. 1.2. QIF validation case studies

1.6 References

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