Digital Metrology Standards Consortium DMSC

Why QIF Matters – A Roadmap for Digital Manufacturing
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Daniel Campbell
Capvidia
Houston, TX, USA

Curtis Brown
Honeywell FM&T
Kansas City, MO, USA

Robert Brown
Mitutoyo America Corporation
Aurora, IL, USA

Jennifer Herron
Action Engineering
Denver, CO, USA

Ray Admire
QIF Solutions
Arlington, TX, USA

John Horst
NIST
Gaithersburg, MD, USA

Cory Leland
Deere & Co.
Moline, IL, USA

Ray Stahl
KOTEM
Rochester, NY, USA

ABSTRACT

This paper discusses how the ANSI/DMSC Quality Information Framework (QIF) standard provides benefit to the model-based enterprise (MBE) in two important ways: (1) automation of cyber-physical processes, allowing faster realization of higher quality products at lower cost, and (2) by providing traceability of massive quantities of measurement-related data to the authority product definition model. Over the last decade, efforts have been made to develop digital interoperability standards that address the connection points for information transfer through the product lifecycle. Through early work in the Automotive Industry Action Group (AIAG) and the Digital Metrology Standards Consortium (DMSC), new data models have emerged and achieved significant maturity levels.

The benefits of automation and business process systemization are made possible with meaningful, semantic data packaged in the QIF format. With Model Based Definition (MBD) data (i.e., PMI, FT&A, etc.) becoming more commonplace, QIF is becoming an attractive complete and unambiguous MBD delivery mechanism for industrial end users. In addition to automation benefits, QIF helps to provide data traceability in this age of Big Data, where traceability is sorely needed. MBE provides a paradigm for organizing this data by mapping it all to a meaningful product definition: the master model-based definition enabled by a product data management system. QIF is designed to instantiate this MBE approach to data management.

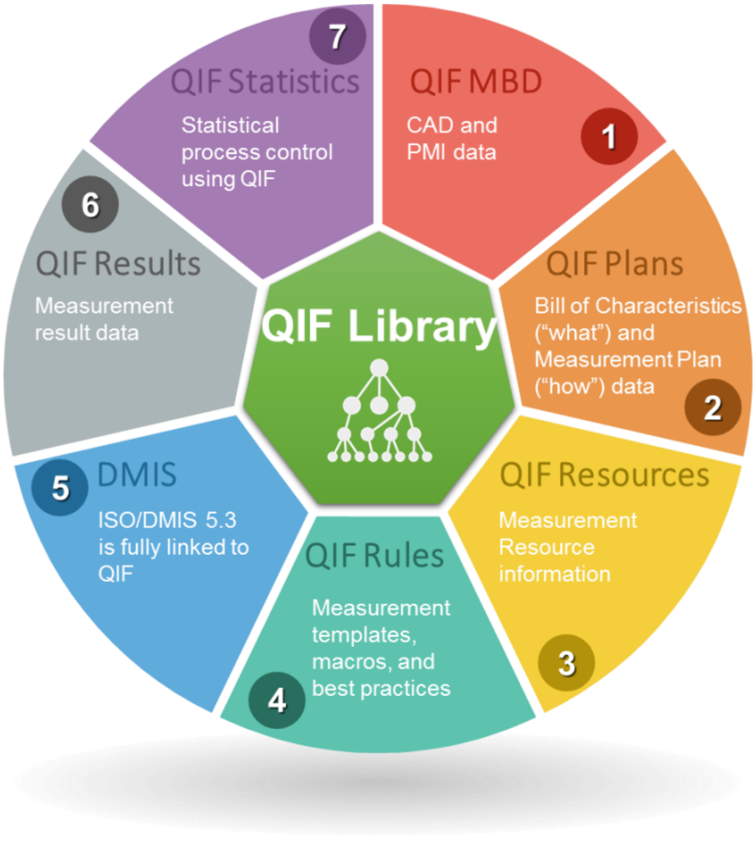
This paper will explain the background for why QIF is needed, and the features built into QIF which will ensure that it is equipped to handle the needs of modern industry.

BACKGROUND

Today's manufacturing enterprise is plagued with the problem of disconnected, disorganized, and duplicated data. Furthermore, recent advances have seen an exponential increase in the volume of industrial data being generated, particularly data related to computer-controlled systems of all types. Terms like "Industrial Internet of Things" (IIoT) and "Industrie 4.0" describe this revolution in big data. However, fundamental issues exist that need resolution. First, the majority of data is only minimally accessible and is unable to be mapped to data from other domains of a manufacturing enterprise. For example, how does raw data collected from a sensor embedded in a jet engine gets mapped to the machine tool operation which machined the blades or the shaft of the engine? A mapping of this type would require a human-in-the-loop to carry out the association based on a tedious study of the part serial number, then a review of the records for the manufacturing process, then the machine tool reporting logs, and finally then a hand-generated mapping to the machining of the feature in question. Reliance on a human-in-the-loop presents the following issues: it is a tedious process of high cognitive load which introduces errors, it is costly, it is not an efficient use of engineer's time, and it prevents software algorithms for automatically mining the data for meaningful patterns and anomalies. A second fundamental problem faced in the field of industrial big data is the inaccessibility of the different data formats encountered. Data is stored in a variety of file formats (e.g., PDF, TXT, TIF, CSV, XLS, STEP, JT, IGES, PRT, QIF, XML, etc.). Some of these formats are proprietary, and require costly software tools to access the data. Other formats are common for archival, but are of minimal utility for software data mining (e.g., a coordinate measuring machine (CMM) inspection report stored in PDF format). Therefore, the issue of non-robust data formats prevents industry from easily connecting troves of data to the digital thread.

THE QUALITY INFORMATION FRAMEWORK (QIF)

The Quality Information Framework (QIF) was created by a group of manufacturers, software and hardware vendors, and metrology experts within the Digital Metrology Standards Consortium (DMSC) as a response to this dilemma. QIF is a feature-based ontology of manufacturing metadata, built on XML technology, with the foundational requirement of maintaining traceability of all metadata to the "single source of truth" – the product and all its components as defined in CAD/MBD. It is an open, ANSI standard which includes support for a complete semantic derivative Model Based Definition (MBD) model, measurement planning information, and measurement results information. This characterization allows users to establish a Digital Twin by capturing the duality of aspects of manufacturing data: the as-designed product, and the as-manufactured product – including the mappings between the two aspects.



The full listing of the application areas of QIF are as follows:

QIF MBD	Derivative model with support for robust, semantic PMI, metrology features, and mappings back to the native model
QIF Plans	Typically considered to be the "Bill of Characteristics" (that which will be measured) and the Measurement Plan (how it will be measured – at a high level)
QIF Resources	Specification of available measurement resources (e.g., CMMs, calipers, scanners, gages)
QIF Rules	Measurement "templates", macros, organizational best practices for measurement, etc.

(DMIS)	DMIS is *not* a part of the QIF standard, and addresses a much lower level of technology. However, harmonization between DMIS and QIF has been built into the latest DMIS release to allow for full traceability to the authority CAD model from a DMIS program – enabled by QIF data traceability
QIF Results	Measurement result data
QIF Statistics	Statistical process control methods and outcomes

The primary benefits of QIF can be thought of relative to the direction of data flow to and from the “single source of truth” (CAD): downstream benefits from CAD (particularly the manufacturing and quality validation processes), and upstream benefits back to CAD.

DOWNSTREAM BENEFITS OF QIF

Modern manufacturing is heavily reliant on *process*. A large manufacturing enterprise is made up of thousands of engineers, each with their own field of expertise. In addition, it is common for *well more than 80%* of manufacturing to take place externally to an OEM as a first-tier supplier, second-tier supplier, or even farther up the supply chain. For a system of such complexity to function efficiently, a strict and rigorous process must define interactions and workflows. Therefore, an OEM’s capability to produce both a high-quality product at a minimum cost and their ability to measure key performance indicators, is directly tied to the structured process for their manufacturing operations.

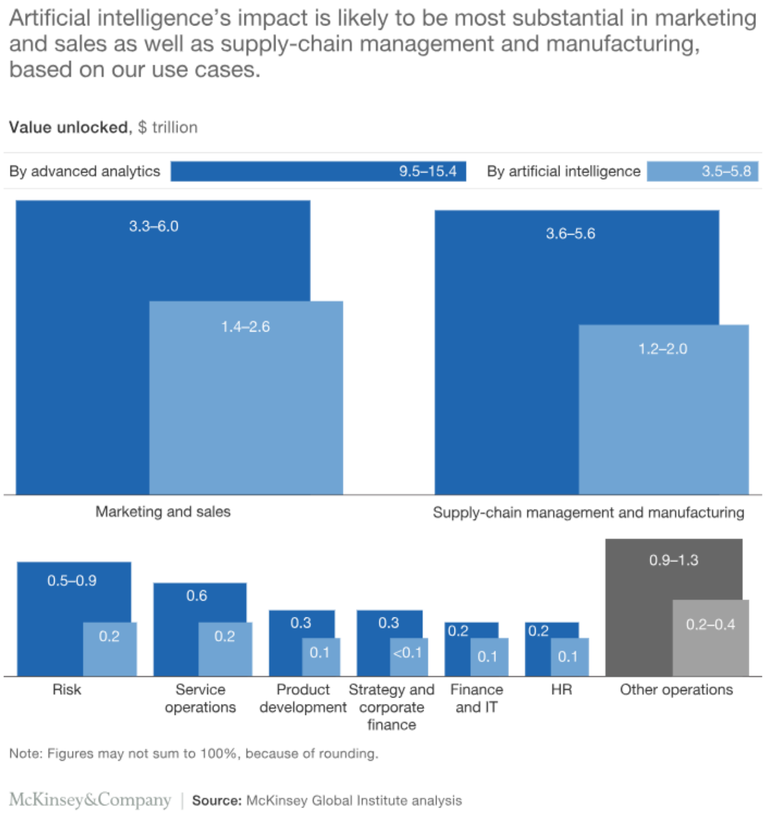
Current processes in the metrology domain are heavily reliant on a human-in-the-loop, which runs counter to the idea of automated process-driven manufacturing. To the extent that an engineer is needed for translation, interpretation, or re-entry of data, the knowledge and practices of that individual will play a large role in the result, leading to arbitrary outcomes and the likelihood for introduction of errors arising from a lack of standardization. (In addition to this, these are hardly tasks which require the types of innovation for which an engineer is best suited, making it a waste of time). An example of this type of inefficiency in metrology is the predominance of the 2D static drawing. The typical process for creating a CMM program, for example, is to load a *shape-only* derivative model with *unknown pedigree* into the CMM software, and then *manually* confirm that the model matches the 2D drawing and then *manually* enter the GD&T information from the 2D drawing into the CMM software. This is time consuming, error prone, and leaves space for interpretation by the operator. This is why the ability to transmit this GD&T data directly and semantically from the CAD model’s PMI is such a crucial feature of QIF: it ensures that data stays intact throughout downstream systems, helping to add structure to a manufacturing process.

In addition to the basic value of adding structure to a process, this XML-based approach can be leveraged to drive automation of software and cyber-physical systems. In a pilot study carried out at Raytheon, a comparison of an MBD-based process, powered by QIF, was compared to a traditional 2D drawing based workflow. In this study, it was determined that a QIF approach reduced the amount of time needed to create CMM programs by more than 80%. Another benchmark study conducted by Rockwell Collins and NIST found nearly 90%-time savings. We expect to see more software automation along these lines as the industry becomes more and more accustomed to MBD.

UPSTREAM BENEFITS OF QIF

The “upstream” benefits of QIF are derived from the quality of the data for analysis. That’s why a critical design objective of QIF is that the data should be *structured*. QIF is a highly organized grammar and vocabulary for software systems to communicate manufacturing data structures. With software interoperability as the goal, and vendors and end-users available to verify (through both pilot studies and production-system deployments), QIF was put under the ultimate stress-test that the data is truly *semantic*. Another important design objective is data traceability to the authority product definition model. Each piece of metadata in a QIF dataset is mapped to the owning GD&T, feature, and model surface in the authority CAD model. This high-resolution mapping to the “single source of truth” ensures that any other data derived from the model can be traced through a graph to the mass of QIF data. This is why QIF matters beyond just metrology: it provides the mapping to metrology data for the entire Model Based Enterprise.

Ultimately, data must be structured and connected to other key data (i.e., the authority model) in order to make it ideal for advanced analytics, artificial intelligence (AI), and data mining. Imagine, as an exercise, a terabyte of ".DAT" files with raw data dumps from a machine tool or CMM. While there is certainly a large amount of data present, there is little *context* to the data, so it is of relatively little value.


Artificial intelligence's impact is likely to be most substantial in marketing and sales as well as supply-chain management and manufacturing, based on our use cases.

Note: Figures may not sum to 100%, because of rounding.

McKinsey&Company | **Source:** McKinsey Global Institute analysis

The value added to industry from the growing fields of AI and advanced analytics are expected to rise sharply over the next few years. According to a McKinsey Global Institute study: "*We estimate that the AI techniques we cite in this briefing together have the potential to create between $3.5 trillion and $5.8 trillion in value annually across nine business functions in 19 industries. This constitutes about 40 percent of the overall $9.5 trillion to $15.4 trillion annual impact that could potentially be enabled by all analytical techniques*". Of all the sectors examined by this study, supply-chain management and manufacturing sector received the second most benefit – for a total estimated value of somewhere between $4.8 and $7.6 trillion.

The prerequisite to realize this value is structured and mapped data. QIF's robust semantic nature, and its strong mappings to the authority model make it a rich target for this type of advanced analytics and feedback to design.

QIF ROADMAP FOR SUCCESS

The DMSC has adopted a depth-first approach to ensuring the continued viability and further success of the QIF standard. Below are some of the pillars of the DMSC's approach to the propagation of the QIF standard.

Continued development of QIF schemas

The software vocabulary and grammar of QIF is defined by the QIF XML Schema Definition Language (XSDL) schemas. These schemas are at the core of what define QIF. The quality of the schemas is of the highest importance to the DMSC. The QIF Working Group is actively attended by influential members of large industrial end user organizations, software and hardware vendors, and prominent academics. Their constant input and effort are what ensures that QIF is capable of transmitting data from real-world manufacturing workflows, and that QIF meets the needs of industry. QIF is currently deployed in production systems and pilot projects in a wide range of manufacturing sectors, and this real-world feedback has been instrumental to ensuring that QIF has the capabilities required by industry. In addition, QIF has opened up research opportunities within the digital thread that will allow for more innovative transformation of the manufacturing space in the future. These priorities will remain at the forefront of the DMSC's priorities.

Data integrity

In this age of data, the questions of data trustworthiness and provenance are paramount. In order for QIF to reasonably fit into the larger picture of Model Based Enterprise, the DMSC has put a large amount of effort into addressing these questions. At a high level, there are three primary pillars to QIF's approach to these data quality: XSD validation, XSLT integrity checks, and digital signatures.

XML Schema Definition (XSD) validation is a test where a QIF instance file is checked for validity to the QIF digital "language" defined in the QIF schemas. This test ensures the interoperability of QIF data from one software system to another. This basic validation gate is the most basic and fundamental check to ensure connectivity of QIF data to MBE at large. Future plans for DMSC propagation of this validation testing includes the release of a free, publicly accessible tool that will make QIF instance file validation extremely easy to end users.

Extensible Stylesheet Language Transformations (XSLT) is a Turing-complete language for processing XML files. Included with QIF is a set of XSLT scripts which are capable of carrying out integrity checks on QIF instance files that are not possible with a simple XSD validation test. A few types of checks currently exist. There are checks to ensure the validity of the structure of the data itself (e.g., making sure that links to external IDs in other documents truly exist, or ensuring that the number of elements contained in a set is correct). There are checks to verify the quality of the data contained in a QIF files (e.g., the quality of a NURBs surface contained in the file). And finally, there are checks to examine the semantics of the data contained in a QIF file (e.g., that a Feature Nominal should have a geometric definition). These checks help to ensure the integrity of the data and assure its usefulness and reliability within the enterprise at large.

Finally, QIF has the ability to control the provenance of the data via digital signatures. This infrastructure helps to ensure that QIF instance files can be imbued with the trust necessary to use it throughout the product lifecycle. NIST has developed an open source toolkit which is capable of creating digital signatures for manufacturing data, and future DMSC efforts will propagate the use of digital signature on QIF instance files by providing sample workflows and how-to documentation on adding digital signatures to QIF instance files.

Integration with current and emerging digital standards

Several of the manufacturing processes are defining digital information appropriate to the semantic and flow requirements of each process. For example, efforts are underway to integrate QIF with the MTConnect specification (mtconnect.org) for certain manufacturing systems, including machine tools and in-process verifications. Furthermore, robotic systems are being increasingly used in manufacturing operations for inspection operations, and certain digital standards (e.g. ROS-Industrial (rosindustrial.org)), will need to be integrated with QIF.

Facilitate software development for QIF

For the propagation of QIF data throughout a manufacturing enterprise to be successful, it is crucial that key software systems be able to "speak the language" of QIF. This is a problem that is faced by any emerging standard data format. Software and custom scripting are becoming more and more common every day, and most recent college engineering graduates have some form of experience with software programming. For this reason, the DMSC has made implementation of support for reading and writing QIF files easy with source code bindings for C++, C#, and Python. These are freely available and open source. Within a matter of a few hours, a developer can be quickly transferring software data structures to and from QIF instance files. With this capability, it opens up the door to an array of opportunities: software vendors can quickly prototype a QIF implementation to understand its capabilities, software vendors can build formal support for QIF with minimal effort, and even end users can write their own code to carry out data mining of a QIF data lake in a high-level scripting language like Python. These source code bindings have helped ensure that QIF is fully immersed in the economy of software tools being used throughout the digital thread for manufacturing. In the future, expect more robust software bindings, examples files, and tutorials from the DMSC.

Free open source tools for QIF

The DMSC plans to help the QIF user community by providing free and open source tools for creating and editing QIF Resources and QIF Rules instance files. These particular types of instance files stand apart from QIF MBD, Plans, Results, or Statistics files in that they are a bit more static in nature than data pertaining to a specific model, serial number, or batch of parts. Generally speaking, Resources and Rules instance files would be created by an organization to be consumed by QIF-enabled software, and would not be heavily modified or updated. For this reason, in the future we will see open source tools for authoring and editing QIF Resources and Rules instance files made available to QIF users and software implementers.

QIF community

The active QIF community has been a pillar of the continued success of QIF. Organized through the DMSC, the QIF community is led by the foremost experts in digital metrology in industry. This community is passionate about digital metrology and QIF, and has banded together to advance the digital exchange of data throughout enterprise via QIF. Members of the QIF community come together to cross-pollinate with QIF implementation and workflow ideas, with mutual support for Model Based Enterprise journeys, future QIF implementation and direction, and general community. This community is active on the internet, in bi-weekly DMSC meetings, and in in-person working group and social events. This community passion, coupled with DMSC outreach efforts on behalf of QIF, are what has helped to catapult QIF's success.

CONCLUSION

The tapestry of software systems, hardware, data formats, and people that make up a Model Based Enterprise is a massive and complex ecosystem. Metrology – the domain of a manufacturing enterprise which by its very nature gathers the most high-quality data related to a manufactured good – is a key part of this tapestry. This is why QIF is essential. The roadmap for QIF is to ensure that it fits into the Model Based Enterprise at large. This requires that is has both a goal to address the vertical requirements (a semantic ontology of metrology data which truly reflects industry real industry workflows), and a goal to address the horizontal requirements (connectivity and trustworthiness of QIF data within the larger context of a Model Based Enterprise). With these goals in mind, expect to see QIF fill a crucial role in the product lifecycle management regimes of a Model Based Enterprise.

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