Driving New Value and Innovation with QIF

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The term "digital transformation" is used in business to describe the use of digital technology to radically improve the performance or reach of enterprises. It is, at its core, about process digitization and the strategic use of information to *drive new value*.

QIF (the Quality Information Framework) is an open ANSI standard for manufacturing, designed to support the digital transformation of quality inspection. *QIF is a major step forward in enabling fully-digital quality inspection processes, and in supporting the strategic use of quality information throughout the enterprise and the product development process.*

Fundamental Challenge

The fundamental challenge in transforming quality inspection into a fully digital process is interoperability.[1] While interoperability is often thought of as merely the ability to exchange computer processable data between different components of a system, in the case of quality inspection, this is not enough. To be fully useful, the data must flow seamlessly into, through, and out of the system.

If you examine a quality inspection system from a high-level perspective, it can be thought of as supporting four major activities, each implemented as a number of components:

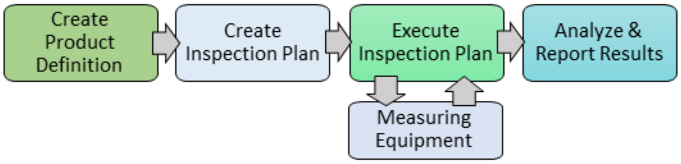

Figure 1 – Major quality inspection activities

What is not shown in the figure is that the major inputs to quality inspection are from design and manufacturing. In fact, quality inspection is where your design and manufacturing processes are made accountable.

With a fully capable quality inspection system, the inspection results for any characteristic of a part are not only traceable to the measuring equipment used to generate them, but also to the manufacturing processes used to create the characteristic, as well as the features in the authority dataset (CAD master model) used to define it.

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[1] The concepts of quality inspection, and dimensional metrology (synonymous with dimensional inspection) are closely related.

This level of accountability cannot be achieved with a piecemeal approach to interoperability, focused on just exchanging data. Interoperability and connected data is only possible with an integrated approach, focused on semantics, traceability, validation, and the seamless flow of data.

This integrated approach is what QIF is all about and showcases its benefits.

Enabling Digital Quality

A prerequisite for digitizing any process is to create a vocabulary (or ontology) of its terminology and semantics. This vocabulary must be carefully modeled, based on a thorough knowledge of the problem.

Consider this simplified view of a typical quality inspection process, using digital measuring equipment (e.g., a CMM).

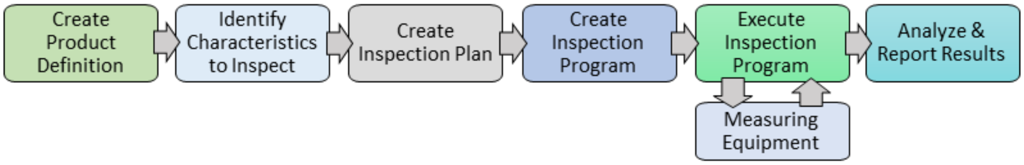

Figure 2 - A simplified quality inspection process

For each activity in the workflow, there is associated information, which may be inputs from external sources, knowledgebase information, or outputs. This figure shows the most prominent categories of quality information associated with each activity:

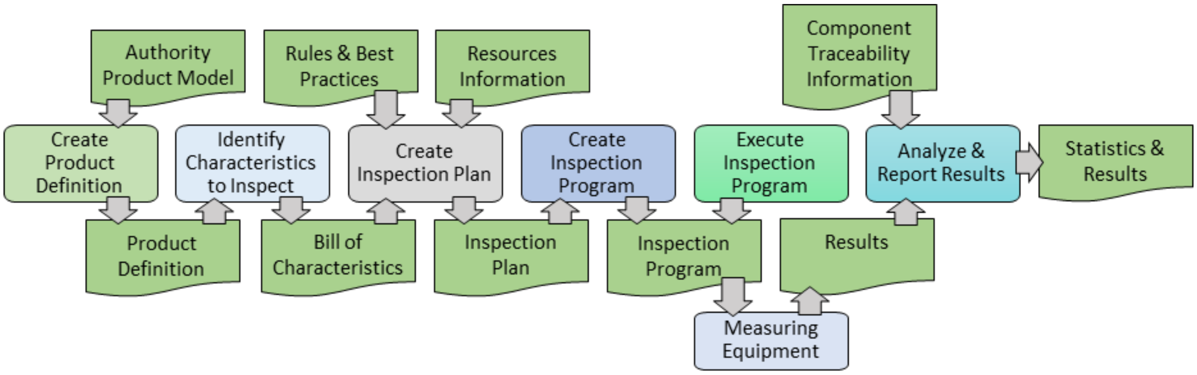

Figure 3 - Categories of quality data

QIF defines an extensive framework of interoperable data models, providing coverage of virtually all quality information and semantics used in quality inspection workflows. It supports semantic interoperability throughout the extended quality inspection process, providing the flexibility to seamlessly combine applications from multiple vendors. QIF promotes quality inspection potential for innovation in areas such as planning, analysis, and optimization.

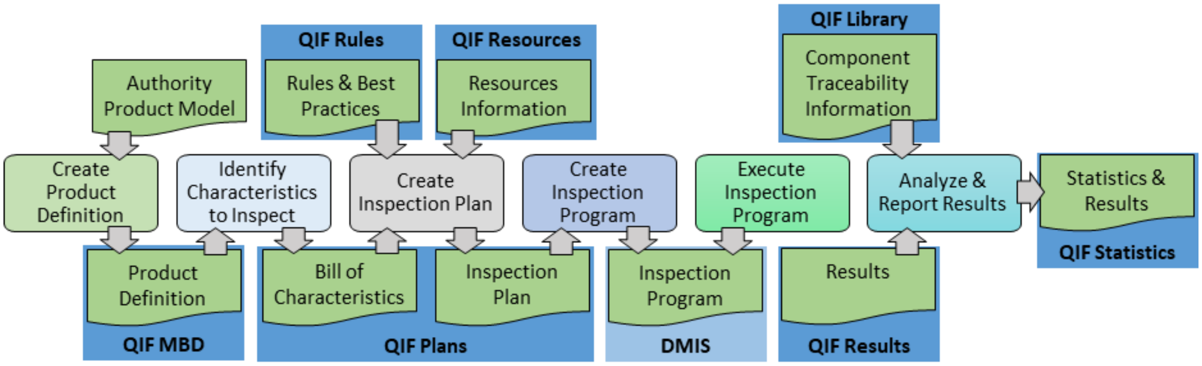

Figure 4 - QIF coverage of quality information categories

QIF also respects formal and de facto standards:

- It is implemented in standard XML, to make integration with other systems easy
- It interoperates seamlessly with DMIS, the international standard for digital measuring equipment programming
- Its product definition language (QIF MBD) is designed to work seamlessly with 3D CAD systems and other sources of product models, such as scanned data and drawings.

Digitizing Product Definition

Quality inspection doesn't happen in a vacuum. It's part of the larger product development ecosystem, including, most notably, design and manufacturing:

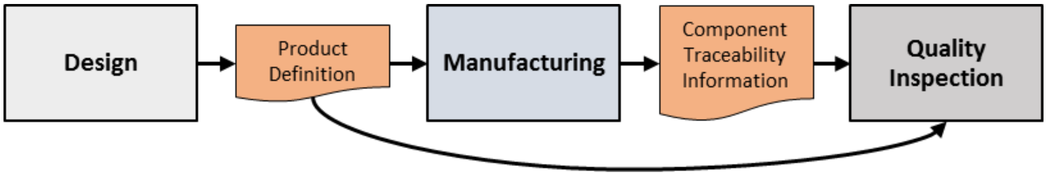

Figure 5 - The product development ecosystem adjacent to quality inspection

While quality inspection consumes data from multiple sources, its most critical input is the authority product model (or, more generally, dataset), describing a component or product, as designed. These data sources come in multiple forms, including drawings, scans of physical models, 3D printing files, triangulated meshes, and, most importantly, 3D CAD models—with or without PMI.

The QIF MBD data model:

- Supports multiple geometric representations, including wireframe geometry, faceted 3D, precise 3D NURBS boundary representation (BRep), and 3D point clouds
- Provides traceability to the authority dataset, including support for digital signatures
- Supports direct mapping of geometry, topology, PMI, and annotations to major CAD systems (CATIA, NX, Creo, SolidWorks) and neutral formats (STEP AP242)
- Supports fine grained object-level traceability to CAD model internal object identifiers
- Allows the tracking of version differences in authority data

- Includes extensive validation criteria
- Includes full support for feature-based semantic PMI
- Is expressly designed to enable the use of model-based definitions in digital data-driven Model-Based Enterprise (MBE) processes

QIF MBD is designed to support many use cases, including:

- Authority datasets that are not machine processable
- Authority datasets that are accessible only through an API
- Authority datasets that are accessible only through derivative files
- Authority datasets that are incomplete
- Authority datasets that are revised/updated
- Authority datasets without PMI
- Authority datasets with partial PMI

Because QIF MBD has the capacity to fully represent the geometry, topology, PMI, and annotations of major native CAD file formats, and supports traceability, validation, and digital signing, it can serve as a trusted derivative file format for applications beyond quality inspection. Because it is a fully documented ANSI standard, it can even serve as a long-term archival format.

Communicating Via the Digital Thread

The notion of a digital thread is generally thought of as a communications framework, connecting traditionally siloed elements in manufacturing processes, and providing an integrated view of an asset (e.g., a component) throughout its lifecycle.

While fully digital data-driven processes are a prerequisite for supporting digital threads, they're only a starting point. A key requirement is end-to-end **traceability**.

QIF includes extensive support for traceability, not as a consequence of design, but rather by intention because traceability is an inherent requirement of quality processes.

QIF implements traceability through built-in traceability elements, validation criteria, persistent identifiers, digital signatures, and semantic links to source (authority) data sets.

A single feature on an individual component can be traced back through its inspection process, through its manufacturing process, and even back to the version of CAD file and specific geometry that was used to define it. Or, a single feature in a particular version of a CAD file can be traced forward, through the manufacturing and inspection process, to the specific components built using it.

The Digital Thread allows for fine grained feedback and feedforward between design, manufacturing, and quality inspection – enabling design for manufacturing, design for inspection, and many other possible process optimizations.

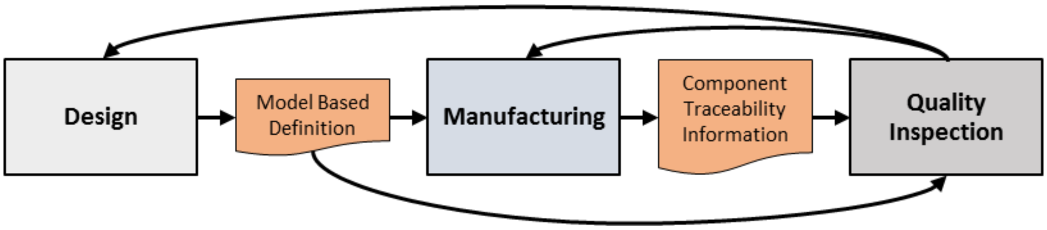

Figure 6 – Digital Thread allows quality data feedback to design and manufacturing

Exploiting the Digital Twin

Dr. Michael Grieves, who introduced the concept of a Digital Twin, defines it as:

> *"A set of virtual information constructs that fully describe a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level. At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its Digital Twin."*[2]

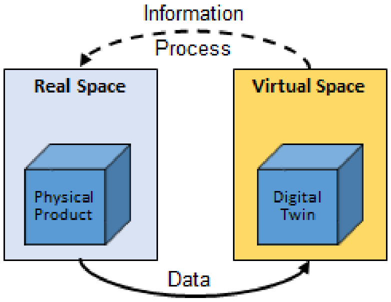

Figure 7 - The physical product and its digital twin

Digital Twins may contain a variety of information, including, but not limited to, fully annotated 3D models, bills of materials (listing current and past components), bills of processes, inspection results, service records, and operational states captured from sensor data.

The value of a Digital Twin comes from using the information it contains in innovative ways to gain insight and create actionable information. Implicit in this is a requirement that the information is structured in a way that it can actually be used throughout the product's lifecycle.

While no single data format is extensive enough to represent all the information that might be contained in a Digital Twin, QIF provides significant coverage, including:

- Fully annotated 3D models, with precise and lightweight representation, semantic PMI, and links to the authority (master) CAD model
- Bill of characteristics (BoC) representing criticalities and measurable characteristics
- Quality inspection and manufacturing process information
- Nominal (as designed) and actual (as measured) values for physical characteristics
- Extensive support for traceability, with unique identifiers and digital signatures

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[2] Dr. Grieves attributes the term "Digital Twin" to John Vickers of NASA. See: Dr. Michael Grieves and John Vickers, "Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems," (2016) Excerpted from "Trans-Disciplinary Perspectives on System Complexity," also, Dr. Michael Grieves, "Digital Twin: Manufacturing Excellence through Virtual Factory Replication."

- Well-documented XML schemas, designed to support easy data reuse and integration
- Completely open standard

QIF provides an optimal data structure to represent physical part and assembly data in a Digital Twin. And, because QIF data is created as part of quality inspection processes, there is no incremental cost to use it as the foundation for a Digital Twin.

Designed for Openness

QIF was designed recognizing that information is a valuable resource and a strategic asset for manufacturers, their partners, and their customers. In order to take full advantage of its information resources, manufacturers must manage information as an asset throughout its lifecycle to promote openness and interoperability. **Managing information as an asset** increases operational efficiencies, reduces costs, improves quality and services, and supports business goals.

QIF is built using industry standard XML technology, allowing it to be automatically processed and read by computer, without any loss of semantic meaning, using easily available tools. Its data structures are well-documented, non-proprietary, and designed to be accessible, discoverable, and usable by not just professional software developers, but also end users. As importantly, QIF is IT friendly.

QIF data is semantic, contextual, traceable, validatable, and, as a result, highly reusable. It is easily integrated into smart data, big data, advanced analytics, and other enterprise systems.

For manufacturers, QIF is a robust and well-tested standard. At the 2014 and 2016 IMTS shows, a group of vendors demonstrated perfect interoperability between multiple commercial-off-the-shelf QIF enabled applications.

For Software Developers, QIF is designed to solve the non-value-added problems associated with developing quality inspection or MBD/MBE applications, allowing you to focus on innovation. The entire QIF data model is open for your use, with no proprietary structures or hidden gotchas.

How to Get Started

QIF was developed by the Digital Metrology Standards Consortium (DMSC), a standards body comprised of quality and engineering software experts from industry, academia, and government.

We invite you to join us in extending, improving and building awareness of QIF.

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Glossary

3D NURBS – Non-Uniform Rational B-Splines, are mathematical representations of 3-D geometry that can accurately describe any shape from a simple 2-D line, circle, arc, or curve to the most complex 3-D organic free-form surface or solid.

3D Point Clouds – A large collection of points acquired by 3D laser scanners or other technologies to create 3D representations of physical structures.

ANSI – American National Standards Institute is a premier source for timely, relevant, actionable information on national, regional, international standards and conformity assessment issues.

API – Application programming interface is a set of subroutine definitions, protocols, and tools for building application software, and is a set of clearly defined methods of communication between various software components.

Annotations – Additional information for drawing views that complete documentation of a digital prototype.

Bill of Characteristics (BoC) – A comprehensive list of all features that comprise and describe a part.

Boundary Representation (BRep) – An extension of a wireframe model that is a solid bounded (represented) by an organized collection of connected surface elements.

CMM – Coordinate Measuring Machine is a device used for measuring the physical geometrical characteristics of an object.

DMIS – The Dimensional Measuring Interface Standard enables coordinate measuring machines (**CMMs**) to communicate with each other.

Digital Twin – The digital representation of physical objects using 3D CAD models, asset models, and process simulations to ensure and validate manufacturability.

Faceted 3D – Three dimensional polyhedrons comprised of polygons whose corners are vertices of the polyhedrons, and not faces.

Model-Based Enterprise (MBE) – A manufacturing strategy that uses an annotated 3D model as the authoritative information source for all activities in a product's lifecycle.

Ontology – Compartmentalizes the variables needed for a set of computations and establishes the relationships between them.

PMI – Product Manufacturing Information is used in 3D CAD and product development to convey design information for manufacturing and includes information such as geometric dimensioning and tolerancing (GD&T), text annotations, surface finish, and material specifications.

QIF – Quality Information Framework is an open ANSI standard for manufacturing, designed to support the digital transformation of quality inspection.

QIF MBD – Defines a digital data format to convey part geometry (typically called the CAD model) and information to be consumed by downstream manufacturing quality processes, such as PMI.

Schema – A diagrammatic representation used to present a structured framework or plan.

Semantic PMI – Annotations and attributes that are associated with a 3D solid model and its geometric features, is software interpretable, and can be displayed for human interpretation.

STEP AP242 – The merging of two standards (one for automotive and one for aerospace) for managing model-based 3D engineering practices.

Topology – Also called rubber-sheet geometry, topology studies properties of spaces that never change under any continuous deformation, because the objects can be stretched and contracted like rubber, but cannot be broken.

Triangulated Mesh – Objects comprised of three types of elements – vertices, edges, and triangles.

Wireframe Geometry – A method for simplistically representing a solid model object with points and lines.

XML – The eXtensible Markup Language is a simple text-based format for representing structured information, such as documents, data, configurations, etc.