# From a digital calibration certificate to a digital quality infrastructure

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**Abstract.** Digitalizing the quality infrastructure is a very substantial objective for public and industrial stakeholders. A huge variety of quality related documents exist and need to be considered and transformed thoroughly into an appropriate digital representation. Early initiatives were started to digitalize the calibration certificate and the international system of units. GEMIMEG-II was a German lighthouse project with industry partners to verify and enhance the concept of digital calibration certificates for different industrial use-cases. Fundamental requirements of a digital quality document concern the standardisation of content regarding semantics, ontologies and the ability to proof originality and authenticity for all digital quality related documents. A versatile digital quality infrastructure benefits from a common structural concept supporting the variety of quality related documents and bears synergies for commonalities in content. The DX document schema and its underlying norms and standards can serve as a common conceptual framework to generate harmonized quality related digital documents and to exploit the data contained efficiently and unambiguously. International applicability and industrial processes require an efficient, productive and process integrable digital quality infrastructure. Functional requirements and opportunities of a harmonized approach for digital quality related documents will be discussed in depth.

## 1 Introduction

Product conformity and calibrations are central elements to prove proper design and functionality of a product. Thus, they are core elements needed in a digital quality infrastructure (QI). The German lighthouse project GEMIMEG-II [1], [2] focussed on the application of Digital Calibration Certificates (DCC) in industrial use-cases. The application scenarios were representative for four branches of industry: manufacturing industry, process industry, calibration service providers and autonomous driving. Furthermore, a legal simulation study challenged and approved the evidential value of a digitally signed DCC in comparison to a paper- or pdf-based calibration certificate. The study simulated a court case about a hypothetical damaging event.

QI-Digital is another German lighthouse project to develop concepts and first implementations for a digital quality infrastructure [3]. This project focusses on digitalization of further quality documents like Certificate of Conformity (DCoC), Digital Test Certificate (DTC) and Digital Reference Material Certificates (DRMC). These additional documents were developed based on the actual status of the DCC. GEMIMEG-II and QI-Digital were aligned and complement each other in scope and content.

Digitalization in industry follows the concepts of federated dataspaces for data exchange along process chains and the asset administration shell (AAS) with its respective and dedicated sub-models to supply and receive well-structured datasets [4]. This will eliminate todays' tedious effort to handle and register documents printed on paper or in pdf-data formats [5] and to extract information and data manually.

Legislation in Europe and other parts of the world enforces a fully digital product documentation containing all information in a digital product passport (DPP) [6]. The DPP contains data on resource consumption and data from manufacturing, for customer information and documentation, service and spare parts and finally end of life information for re-use, disassembly and recycling. Product passports come into force for the battery in 02.2027 and for a large variety of industrial products until 2030. To comply with these regulations, data required in the passports can be retrieved from the asset administrations shell and its respective sub-models.

Quality documents like DCoC, DCC, DTC and DRMC are typically passed through to a product customer to prove product quality. As such, they will be part of the AAS and DPP and contained in the AAS sub-model for digital quality documents.

This paper will give more detail on recent and upcoming developments on digital quality documents to enable an efficient digital quality infrastructure.

## 2 Digitalization of quality documents

To digitalize quality documents effectively, some basic but important preconditions have to be considered. Fig. **1** summarizes major needs. The upper part shows

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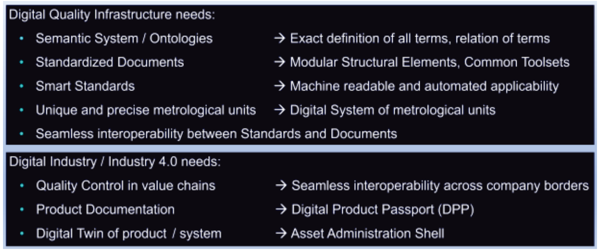


**Fig. 1.** Needs for digitalization from perspective of digital quality infrastructure and from industry [7]©Creative Commons Attribution 4.0 license

needs from a general QI perspective while the lower part reflects complementing requirements from an industry perspective.

The economic value proposition of digital QI is based on seamless and efficient interoperability of all quality documents including immediate access to data and information contained. Essential prerequisites are exact semantic definitions of all terms used in quality documents. International adherence requires publicly available standards. When available, they will guide, support and harmonize the plurality of current digitalization initiatives. Furthermore, the relation of these terms defines their underlying ontology. Since some terms may exist with a different meaning in different contexts or technical fields, it might be favourable to define separate namespace for distinct technical fields. This will increase efficiency in digitalization and reduce tedious and time-consuming alignment, if possible at all.

Normative work can serve as reference point for available semantics and semantic references including ontologies. These references can be explicit definitions or implicit by specifying semantic terms via their relation to other terminology contained, e.g. in kind of knowledge graphs. The latter would be more adaptive and favourable when computer systems and language models should use them, too. An open but maintained normative framework is desirable to represent the perpetually growing sematic content – e.g. in form of maintained and commented repositories with regular release cycles to keep up pace with the fast evolution of digitalization in different technical fields.

A common structural approach for QI documents enables to transform and represent the semantically defined content of the documents in a modular way, even for different document types. Commonly used modules allow to leverage synergy potential across different QI documents for re-used elements. The modular structure also allows for dedicated toolsets to create, handle or use these documents and all data contained.

QI is based on international standards. Smart standards allow for full interoperability between a given standard and a digital quality document related to it. In future, the content and even formulas could be directly referenced from the standard or even used when preparing the content of a quality document like a DCC or a digital test certificate or measurement protocol.

The originality and authenticity of digital documents is of ultimate importance. Previous paper or pdf-based document have a letter head representing the issuer. For digital document it is necessary to replace the letter head of official documents issued by public authorities and accredited test and calibration bodies by a digital mean. A qualified digital signature with a company's credentials or an official digital seal or accreditation symbol could serve as a versatile solution. Automated tests on the validity of the signature or the document can be performed. In contrast to actual regulations, a digital signature should be made compulsory for QI documents.

The QI documentation also needs to be referenced precisely to the system it is linked to. Unique references are needed. In the framework of the digital nameplate [8], a unique product identifier (UID) is introduced. This could be the one unique reference to a system. Legacy system and common practice have different identifiers in place today. The tool owner my issue his identifier for the system and/or the place where it is used in the process and/or a logic name, where the data is supplied to and/or a unique network identification linked to the hardware. Even qualification service providers tend to issue their own UID to support traceability of their service. A digital QI document must be capable to incorporate those different identifiers with an appropriate reference to the issuer or purpose of this reference. To minimise errors and confusion, the number of such references should be kept as small as possible in QI documents. As an example, a temperature sensor could consist of multiple and modular components, the sensor element, the data transmitter including A/D conversion and a display unit as process indicator. When the entire system is calibrated, all three UIDs must be referenced in the DCC, to specify the system unambiguously.

Many quality documents state measurements and test results and thus need a digital representation of metrological units. The Système International d'Unités, the SI-System, is the international system of metrological units as defined in 1875 [9], 150 years ago, as shown in Fig. *2*. Today, it is based on the seven metrological defining constants. The seven base units are derived from theses constants as defined per 2019-05-19. The actual SI system is tracing back via the evolving definitions to its origin of the meter convention in 1875. Since 2024, it is completely transferred into the digital world with the SI reference point of the BIPM [10]. This reference point provides all the information of units in digital form with full history of the definition of units of the metre convention.

Digital documents need definite metrological units in an explicit digital representation to define measures

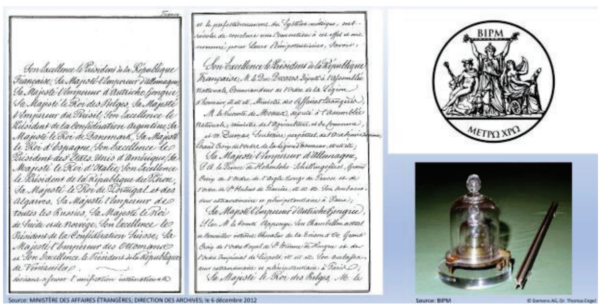


**Fig. 2.** The first two pages of the meter convention listing the undersigning representatives of the member states, physical artifacts for kilogram and meter. [7, BIPM]

for requirements, specify product features and document measurement results properly. The D-SI system is a very systematic schema to define and represent SI units [11], [12], [13]. It is implemented in XML. It contains the 7 base units and all 22 derived units as defined in the SI-brochure [14] of the Bureau International des Poids et Mesures (BIPM).

Furthermore, the D-SI systematic allows to specify additional units, including imperial units. They can simply be defined as a derivate unit with a unit name, eventually short name of the unit and unit symbol. Those derived units are specified by a combination of the base units in the respective power together with a potential scaling factor. Thus, the D-SI is designed to represent all metrical units used. Meanwhile, complementary implementations of digital representation of the SI are developed, e.g. from a BIPM working group. In the end, it is important to have a versatile and unambiguous system to represent all metrological units in use as a digital unit. This system needs to follow strict rules how units get defined and how new units can be added, in case they are needed. This digital system of units should be represented in international norms to harmonize the digital representation of the SI worldwide.

Today, there is the ISO 80000 framework with many units of measurement represented, but not as digital representation. In parallel, there is the IEC 62720 standard for the common data dictionary (CDD) with a section about the units of measurement (UoM). It lists 1822 units of measurement, some of them at least with some digital expression as a formula. Both standards need to revised to incorporate at least one versatile systematic schema for a digital representation of measurement units. The systematic behind the units defined as a derivative of the base units allows for automated conversion of measurement values to other decimal multiples of the same base unit or alternative derived or imperial units. This is a very powerful feature when aggregating data from different sources. Furthermore, the implementation of digital units in a programming language can be decoupled from the sematic and systematic structural definition of units. To implement this systematic representation of a digital SI in computer readable and executable from, appropriate notations like XML or JSON [15], [16] can be used. In addition, it would be favourable, if all seven base units and the 22 derived units of these standards would be linked to the BIPM refence point to provide full metrological definition complementing today's semantic definitions and descriptions in the standards.

All the aspects mentioned above about standardized and homogenized semantics and ontologies for digital quality documents, standardized digital representation of SI units and smart standards aim at a seamless interoperability between standards and documents in QI. They serve as a common basis for ongoing and future digitalization initiatives in QI and industry. These standards will secure the huge investments to be done for an efficient digital transformation of QI and industry.

Industry is digitalizing its processes as the fourth industrial revolution. Thus, the process of quality control will be digitalized to leverage the value

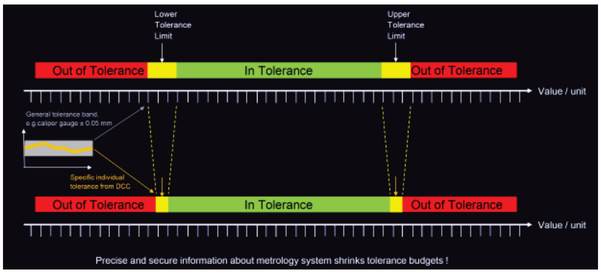


**Fig. 3**. Visualisation of the enlarged "in tolerance" process window with decreasing tolerances of the measuring system. [2, Fig. 2] ©Creative Commons Attribution 4.0 license

associated with the availability of more detailed knowledge in and about a process. Quality information has to be reported in standardized fashion to enable seamless utilization and interoperability of the respective data. The Asset Administration Shell (AAS) is the concept for seamless data provisioning and interchange as structured datasets allowing for machine interoperability and executability.

The benefit of the availability of precise data in a process is sketched in **Fig. 3**. It shows the significant effect, how the operative process window of a conformity control process can be enlarged. The in-tolerance portion is enlarged, when values from standard tolerance classes of the testing system are replaced by the exact values from a calibration. More precise sensor information increases repeatability and reproducibility of related processes. When calibrations are required and performed to qualify accuracy and precision of the testing system, the exact data is reported in the DCC. The whole calibration data can be extracted automatically in full detail from the DCC. The accuracy of sensor data can be improved by software-based adjustments of data measured at no additional cost.

By 2030, a digital product passport (DPP) is mandatory to deliver industrial products in the European Union and even other regions of the world. These legal requirements enforce to make product documentation, resource consumption and lifecycle data available to customers. Quality documents will be part of the DPP. At the end of life, this compiled and detailed information can be used to minimize the environmental impact of a product and to enable a circular economy by reuse or recycling. This full digital documentation of product related data is a contribution to a real world based digital twin of the respective product. The DPP contains design information and lifecycle information, which can be for example a DCC for calibration and other QI documents.

## 3 The DX Document Schema

The concept of a common digital document schema called DX-Schema is introduced in multiple publications [1], [2], [17] in detail. Fig. *4* shows the concept idea of the DX-schema. The aim is to derive multiple QI documents from a common, modular semantic basis DX to leverage synergies, reduce implementation efforts while increasing speed of implementation and the maturity of the solution created. Furthermore, all tools needed to create these digital documents or to extract data and/or information from

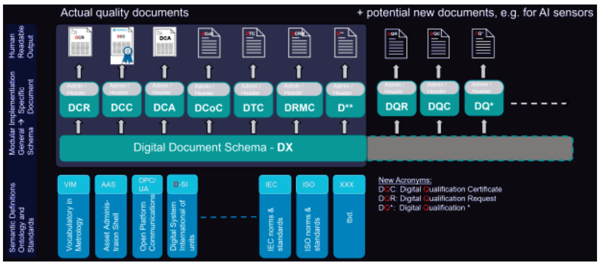


**Fig. 4** : Conceptual view of the digital document schema DX, advanced version of *[7]*, p.10 ©Creative Commons Attribution 4.0 license

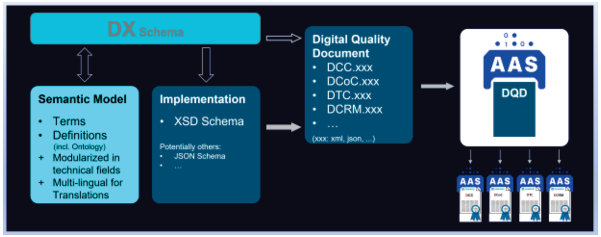


**Fig. 6.** DX-Schema with semantic model, implementation and digital quality document (DQD), advanced version of [2], fig. 6 ©Creative Commons Attribution 4.0 license

these documents can be used for multiple documents and thus further synergies can be unlocked.

A more detailed view on some selected and exemplary norms and standards supporting the DX-schema is shown in Fig. ***5***. Very general and broadly applicable norms and standards are shown in the left column and more specific standards in the right one. The middle part lists some standards closely related to QI and central documents and certificates to be supported.

The concept for implementing DX based quality documents is shown in Fig. ***6***. The DX-schema is a modular structure which contains all sematic definitions and ontologies for the technical terms used for a respective section of a quality document in a separate module. The structure as sketched in Fig. ***5*** represents the underlying modular concept. To apply this semantic structure to create real documents, an implementation in a computer language is needed. When developing the DCC and the d-SI, XML was chosen as language and an XSD schema was created [12], [18] to define basic rules and logic contained in the schema. The value of this schema definition is, that the content of real documents can be checked automatically for completeness of mandatory entries and some logical relationship between selected data fields. This important feature will help to reduce the number of incomplete or false entries. On larger scale, the data quality in a digital QI will be improved significantly. This results in more robust and resilient digital processes as one lever to increase productivity along value chains.

The DX-schema based digital quality documents can be incorporated into the Digital Quality Document (DQD) sub-model for the AAS, as shown on the right side of Fig. ***6***. The common DX schema implies significant synergies to the process, since it reduces or eliminates the need for customized solutions for different quality documents. It reduces implementation and maintenance efforts and related sources of errors.

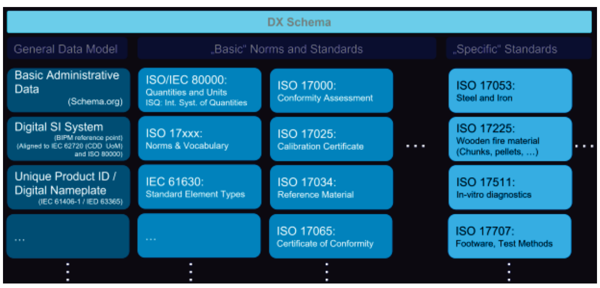


**Fig. 5** : Structural view of norms and standards underlying the DX-schema, advanced version of [2], Fig. 7 ©Creative Commons Attribution 4.0 license

## 4 Value Stream and Quality Information

A digital QI is based on a variety of different quality documents, which are generated along the product value chain during product generation and its lifecycle. It starts in the early design phase of a product with customer requirements and concepts. They get detailed in the design phase to finalize the product. During design verification, production and quality testing, additional proofs and qualifications are done to qualify a product model and/or a specific serialized product. Qualification results get documented systematically as shown in Fig. *7*. It shows schematically various contributions of quality documents from documentation (D), tests (T), qualifications (Q) and calibrations (C) along a generic product generation process. Certificates of Conformity for a product or a product family can also be provided from third party verification and validation of the product design. All these documents are stored in the manufacturer's ERP system or the asset administration shell (AAS) of the respective product. Only documents relevant to the customer get compiled into the digital product passport which is supplied to the customer together with the finished product. Typically, it will be available to the customer via the serialized link of the unique product identifier (UPI) contained on the digital nameplate (DNP) of the respective product. The access to this information is restricted to control the flow of information and protect business secrets.

When the product is in use, recurring qualifications can be mandatory or required by internal provisions or process guideline to secure product quality. **Fig. *8*** shows a use-case typical for recurring calibrations of a sensor to control product or process properties in a production environment. The diagram shows the complexity that a given sensor type can (1) be purchased from alternative suppliers and (2) recalibrated by one service provider at a time, selected from a group of qualified candidates. All documents related to the sensor need to be stored for

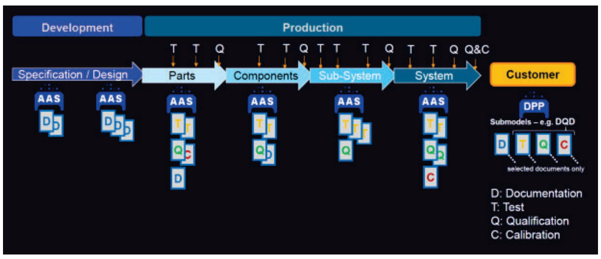


**Fig. 7.** Schematic view of a production line with a sequence of qualification steps and documentation [7], p. 15 ©Creative Commons Attribution 4.0 license

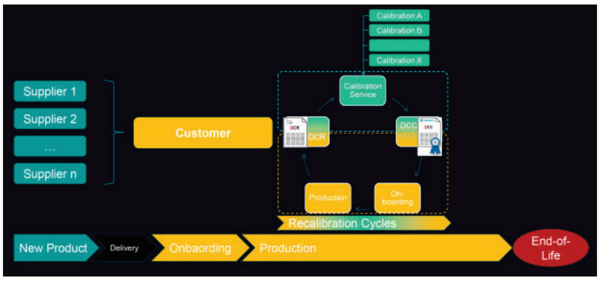


**Fig. 8.** Schematic view of a sensor utilized in a production line with regular calibrations *[7]* ©Creative Commons Attribution 4.0 license

reference and documentation. The AAS and the DPP are based on a common concept to supply and store the data in a systematic way. The AAS sub-model for Digital Quality Documents (DQD) is the conceptual and practical element to properly supply QI documents into the AAS.

Due to the observation that a variety of quality documents can be derived from a common DX-schema as document semantic system and implementation, it was named Digital Quality Document". This new DQD sub-model is listed in the framework of the Industrial Digital Twin Association (IDTA) [4] and close to its first release. Fig. ***9*** shows the example of a DCC as it is represented in the AAS-sub-model.

Every quality document like a DCC is integrated into and attributed to the AAS structure of the respective sensor asset. DQDs can also be part of the DPP of that sensor, where the information is listed as a digital quality document sub-model element. Over the lifetime of a specific sensor, a significant number of such quality documents can accumulate in the respective AAS and DPP from recurring qualifications and calibration performed.

Typically, industrial operations are organized in clearly structures processes representing the underlying value stream. The ambition is, to get the same output of processes irrespective of the individual service provider contributing to this process. This aspiration holds true also for QI processes with different service providers involved. For QI documentation, the expectation is to get the respective quality document with the same content and structure, irrespective of the service provider involved. This can only be achieved if there is a qualified and binding regulation about the content and requirements to be analysed and approved by the requested service. A functional requirement specification is needed as input for the service provider. The client has to provide it as a technical specification.

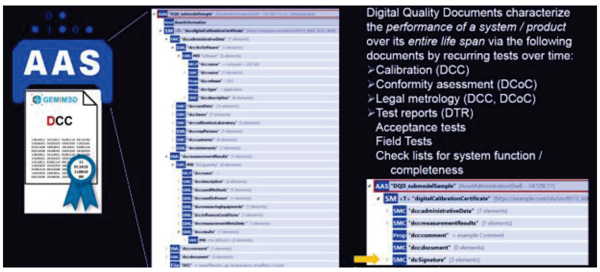


**Fig. 9.** Digital Quality Document (DQD) sub-model with DCCs as part of the Asset Administration Shell AAS [2], Fig. 10 ©Creative Commons Attribution 4.0 license

To receive a calibration certificate with the expected results on e.g. precision of calibration and setpoints used, a calibration request (DCR) needs to be transferred to the service provider. Fig. ***4*** shows, that such a request documents (e.g. DCR and DQR) can also be derived from the DX-schema. Fig. ***8*** gives the example of a DCR on the left side of the feedback loop. Even those request documents can be carried over to the service provider in a DQD dataset of the AAS. Again, benefit is taken from a common structure behind all these documents. The service provider can use the respective request to derive the basic structure of the certificate requested.

To close the feedback loop from a process perspective, the client can use the request specification he issued previously to the service provider. He can double check the final certificate for completeness and correctness of the data contained and thus completion of the qualification task. Full automation at this stage would mean that the invoice from the service provider gets only paid, when this automated check was completed successfully.

## 5 QI in Dataspaces

Dataspaces are the new concept of digital industry to exchange process relevant information in a structured, controlled and traceable manner. The operator of a dataspace has to provide basic services for general operation, user or partner registration, role management to control access rights to information and documents and so forth. Additionally, the operator has to provide a strong digital trust chain as a basis for all transactions to be executed in the dataspace by all participants. Besides classical customer – supplier transactions, there will be roles of market surveillance, quality service providers from accredited bodies, test- and calibration services, legal metrology and auditors. This list is not exhaustive but shows the complexity of the roles, responsibilities and related access rights and permissions involved. Fig. ***10*** depicts the functional elements in a dataspace setting. A typical quality process with request and certificate is shown in the horizontal blue box in the middle, the manufacturer – customer – qualification service provider relation is shown in the green box underneath. The outer blue frame represents the administrative and

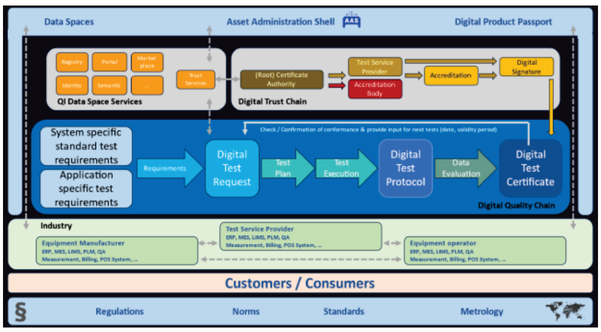


**Fig. 10.** Workflow oriented schematic diagram for calibrations / tests for a digital QI in a digital environment of dataspaces and AAS, including dataspace services and digital trust chain elements. [2]©Creative Commons Attribution 4.0 license

legislative framework. Dataspace administration and digital trust chain elements are shown in the upper bright boxes.

One strength and benefit of the dataspace concept is, that every participant of a dataspace has only to connect once to this dataspace. This reduces the ever-increasing complexity and maintenance effort to support numerous proprietary interfaces between customers and suppliers or service providers. After registration for the role(s) desired, the dataspace operator will check correctness of data and entitlement for the role(s) requested. Then he will grant the respective access rights and permissions. To interact with all other participants of this dataspace, no further registration nor individual or customized interface needs to be set up and maintained. In that respect, a dataspace simplifies the digital data exchange between its participants significantly.

Another benefit of dataspaces is the feature, that market surveillance or notified bodies can have direct access to the data and documents they need to fulfil their role. Since they might have access to business-critical information, a strict and trusted role and access management is mandatory.

## 6 Conclusion and Outlook

A seamlessly digitalized quality infrastructure is imperative for an innovative and competitive industry. The growing demand for product specific reporting on product information, resources integrated and consumed during production and lifecycle information on product performance and operational resources is obvious as a global and regional trend. To counteract climate change by informed utilisation of natural resources, enabling circular economy, reducing paperwork for documenting quality are just some demanding challenges for our economy and society. A digital QI bears a huge potential to improve productivity and process yield in industry by making existing information available and machine executable. A fundamental reduction of paper based documentation and related administrative and storage efforts reduces process cost significantly. Improving accessibility and availability of data bears a variety of chances for further process optimization and future business models.

This paper explored the requirements and chances of a digital QI from an industry perspective at some level of detail. The work was based on the outcome of the GEMIMEG-II project which was reflected with respect to the broader requirements of a digital QI and Industry 4.0 demands. Since the whole field of digitalizing industry is developing rapidly, there will be an ongoing process of adopting and enhancing the concepts and implementations discussed here. Nevertheless, it is worthwhile to share such an elaborate project status as it can serve as a common basis for future enhancements.

The author hopes and encourages, that this generic but practical and broad approach of DX based digital documents for a versatile QI will be supported by international organisations in metrology, conformity assessment and standardisation like e.g. the BIPM); the International Electrotechnical Commission (IEC); the International Organization for Standardization (ISO) and the International Organization of Legal Metrology (OIML).

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