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DEVELOPING AND TESTING DIGITAL CALIBRATION CERTIFICATE IN AN INDUSTRIAL APPLICATION

Juho Nummiluikki [a, *], *Sari Saxholm* [b], *Anu Kärkkäinen* [c], *and Sami Koskinen* [d]

[a] Digital Transformation Specialist, Beamex Oy Ab, Pietarsaari, Finland, Juho.Nummiluikki@beamex.com
[b] Senior Scientist, VTT MIKES, Espoo, Finland, sari.saxholm@vtt.fi
[c] Research Manager, VTT MIKES, Espoo, Finland, anu.karkkainen@vtt.fi
[d] Director of Digital Transformations, Beamex Oy Ab, Pietarsaari, Finland, Sami.Koskinen@beamex.com
* Correspondence: Juho.Nummiluikki@beamex.com

Abstract – Rapid growth of automation generates increasing need for measurement data, provided by sensors, the interface between real and digital world. In Industry 4.0 scheme the measurement data, including the calibration information, flows through the whole production chain in digital format. We demonstrated a fully digitalized environment for the calibration data generation, transfer, and usage in a Proof of Concept (PoC) project. Various stages of the PoC and different information systems used by the partners Aalto University, VTT MIKES, Beamex, Vaisala and Orion are discussed. The developed and tested Digital Calibration Certificate (DCC) solution and its components are described. The major findings of the project include further need of DCC standardization and good practice subschemas. Development of the DCC is ongoing worldwide and the big picture goes even beyond the DCC. It is not only a question of calibration certificates and related data transfer to digital and machine-readable format, but also how this data could be used effectively.

Keywords: calibration, Digital Calibration Certificate, traceability, metrology, digitalization, Quality Infrastructure

1. INTRODUCTION

Western Europe was the third largest region in the measuring and control instruments market worth $137.9 billion in 2020, accounting for 19.6 % of the global measuring and control instruments market, preceded and followed by North America at 27.7 % and Eastern Europe at 5.6 % respectively. The Western Europe measuring and control instruments market is expected to grow to $188.59 billion by 2025. [1] Since only reliable measurement data enables reliable decision making, regular calibration of measuring instruments and the metrological traceability of these results are essential. Additionally, effective processes, calculations without human errors, automated reporting procedures and use of calibration data have indirect economic effects on the industry through better product quality.

In industrial production, the quality of products and processes is verified by measurements. Efficient quality inspection is essential to avoid defect propagation in the manufacturing chain. The target is to minimize waste in the production as well as ensure long lifetime to minimize waste due to premature end product failure [2]. Fully digitalized cyber-physical manufacturing requires autonomous quality inspection and control processes as well as integration to digital design and digital quality certificates, including digital calibration certificates. These principles are also emphasized by Sustainable Development, where the production chain from raw material to recycling (or waste management) of the end product can be digitally controlled with a Digital Twin.

Today calibration certificates are paper documents or PDF files which need human operations in the calibration processes. With help of Digital Calibration Certificate (DCC), manual work with calibration certificates can be eliminated. This makes calibration processes faster and allows valuable human operators to concentrate on more productive work. Data transfer and uncertainty calculations related to calibration results can be performed automatically. Moving towards machine-readable DCC aligns not only with the digitalization strategies of individual organizations but with more comprehensive initiatives such as the European Digital Strategy of the European Commission (EC) [3]. Providing a quality and traceability infrastructure for data-driven engineering in Industry 4.0, the Internet-of-Things, autonomous systems, etc., also requires machine-actionable calibration information, i.e., access and interpretation by computer systems. The DCC information can be directly transferred into other digital processes to optimize process control and hence get the benefits of the calibration data online. Thus, it can be utilized for digital workflows in measurement science, calibration, and industry.

The International System of Units (SI) [4] provides a coherent foundation for the representation and exchange of measurement data. It also enables interoperability and reproducibility in all fields. EMPIR SmartCom project [5] has defined Digital SI (D-SI) [6], where a data format for reporting measurement results in terms of a numerical value, associated unit, and uncertainty statement is described. However, the correct interpretation of this information is only possible by understanding first the content of the SI system, and additionally knowing the GUM [7] about uncertainty, the VIM [8] about the metrological terms, and standards such as ISO/IEC 17025 [9] about concepts like metrological traceability and calibration. This means that all these terms and concepts together with their meanings need to be represented in a machine-interpretable way, to make a DCC machine-readable in a wider sense, and thus enable the new services and possibilities based on digital calibration data.

In this paper, we describe the results of a Proof of Concept (PoC) project that tested a fully digitalized environment for calibration data generation, transfer, and usage. In section 2, we present the stages of the PoC, partners involved in the project, and different information systems used by the partners. In section 3, we describe the developed and tested solution and the components of the solution in detail. In section 4, we discuss about the findings of the project, DCC standardization, future needs for the DCC adoption and future work of the partners.

2. METHODS

Two linked calibrations of a metrological traceability chain were chosen for the PoC. The calibrated device was a humidity and temperature probe type HMB75B, manufactured by Vaisala Oyj. The traceability chain covers the metrological traceability from the SI to the end user working measurement standard. The chosen chain is not fully complete since it does not include the actual measurement results performed by the PoC end user in their real process environment. The PoC was executed with DCC version 2.4.0 [10]. The good practice template used in the project was collectively developed and agreed by the partners in the PoC.

2.1. Testing methods and partners

Proof of Concept (PoC) is a realization of a certain method or idea to demonstrate and find out its feasibility to the meant purpose. The authors saw, that a PoC would be an effective way to test DCC in practice and gain experience. Our PoC included following stages: creation, sending, receiving, and reading the DCC. In addition, special attention was paid to the digital authentication of the data, data integrity and fulfilment of the metrological traceability.

In Finland, a digital data ecosystem has been established with DCC in its focus. The group consist of research institutes, instrument manufacturers, calibration laboratories and end users, i.e., the whole value chain is represented. The common goal is efficient and extensive utilization of measurement and calibration data as well as increasing digitalization in this context. Especially pharmaceutical industry has been active in this field, and the current activities around the DCC are linked together through this sector.

In the PoC reported in this paper, the partners were Aalto University, VTT MIKES, Beamex Oy, Vaisala Oyj and Orion Oyj. Aalto University was the project coordinator and developed the data transfer platform and cloud components for DCC management. VTT MIKES is the National Metrology Institute (NMI) in Finland and provided the expertise of calibration certificates and traceability to the project. Beamex, a leading integrated calibration solution company, was the calibration management system provider in this project. Vaisala manufactures innovative measurement solutions for weather, environment, and industrial processes. The instrument containing humidity and temperature sensors was a product of Vaisala. They operated in the project as an accredited calibration service provider and a DCC receiving party. Pharmaceutical company Orion was the other DCC receiving party and the endpoint of the calibration chain.

2.2. Implementation setup introduction and systems

DCC management and exchange was tested by simulating a traceability chain which included three partners: VTT MIKES, Vaisala and Orion. The PoC concentrated on a humidity and temperature probe used by the calibration end user Orion. The simulation concentrated on the temperature traceability chain.

Each partner in the traceability chain had a different calibration management system (CMS). Calibration certificate generation in VTT MIKES is based on their proprietary inhouse software together with Microsoft Office tools for data management and certificate templates. For their system environment, a manual DCC creation tool was estimated to be the easiest to implement in the project. In the future, the DCC creation can be implemented as a part of their current information management systems to increase automation in DCC generation, but for the PoC this was decided to be out of scope.

Vaisala had a dual role in the PoC as they both received a DCC from the VTT MIKES and sent a DCC to Orion. Vaisala calibration services use a proprietary inhouse calibration management platform. On the DCC receiving end of Vaisala, it was decided by the project consortium to test the manual receiving process. Receiving of the DCC was based on a human readable format of the DCC as described in section 3.2. As the certificate creation process is already highly digitalized within Vaisala's calibration management platform, automated DCC generation was possible to test due to fully machine-readable data. Automated DCC generation was tested as a part of the calibration management platform as explained in section 3.1.

The DCC created by Vaisala was received by the calibration end user Orion. Orion uses a commercial off-the-shelf calibration management system Beamex CMX. DCC import to the CMS was tested as a part of the Beamex CMX environment to enable automated import of calibration results from the DCC. The structure of the DCC import is presented in section 3.2. As each organization had their own CMS, the data transfer needed to be arranged through the organization boarders. In the PoC, the data transfer was tested through a data transfer platform that was integrated into the components used by the partners in the traceability chain. The data transfer platform enabled system-to-system integration of different CMS systems eliminating the need for, e.g., emails as a transfer method.

3. RESULTS

The tested solution created a fully digitalized environment for the calibration data generation, transfer, and usage. The different components and organizations in the traceability chain were integrated to each other through the data transfer platform. As presented in Figure 1, the DCC generation tool in Vaisala and the DCC receiving in Orion's CMS were tested as a part of the organizations' existing information technology environment. Other components of the tested infrastructure were implemented as a part of cloud-based data transfer platform. The calibration traceability chain was created through the DCCs. Each DCC includes all necessary information for traceability e.g., measurement data, deviation, uncertainty, and measurement references.

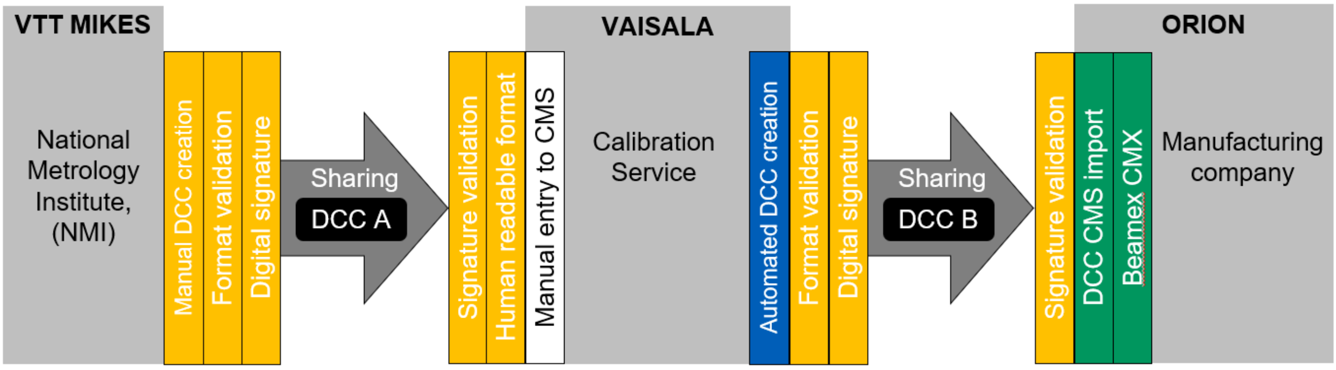

Fig. 1. Data flow and components of the developed and tested solution for Digital Calibration Certificates (DCC). Colour of the component indicates the organization that was responsible for the development. Yellow and dark grey components were developed by Aalto University, blue components by Vaisala and green components by Beamex.

3.1. Components for creation and sending

Manual DCC creation – Global adoption of the DCC format requires easy-to-use tools with low entry barrier. In the PoC, a web form was developed, based on the good practice format of the DCC, for manual creation of DCCs. The web form was developed using JSON GUI technology and it was integrated to the data transfer platform. The web form enabled easy creation of DCCs without any changes to the existing information systems.

Automated DCC creation – Another approach to DCC creation was a fully automated DCC creation from CMS. The component was tested as a part of a laboratory calibration management platform. The component enabled creating a DCC automatically from the calibration management system database. Fully automated DCC creation mitigates human errors in the DCC generation and removes unnecessary work.

Format validation – DCC offers a framework for the calibration data that needs to be specified to a use case in question. The use case specific templates are called good practice DCCs, and they are formed, e.g., to different measurement quantities. Seamless interoperability requires that the use of the DCC schema and the good practice examples are commonly agreed and executed. To ensure this, DCCs need to be verified to make sure that the data format follows the commonly agreed guidelines. Format validation checks the data in the DCC against an XML schema, defined by the DCC schema and the use case specific good practice DCC, and highlights the possible differences. In the PoC, the format validation was implemented as a part of the signature service.

Digital signature – Calibration results need to be authorized by the calibration provider and secured during the transit. A cryptographical digital signature allows the calibration customer to trace the signature to the calibration provider and ensure that the data integrity of the calibration results is intact. In the PoC, cryptographical digital seals were used. Digital seals are digital signatures that identify a group of people instead of one individual person. In the PoC, digital seals were used at organization level. Each organization had their own private keys for signature creation traceable by the demo Public Key Infrastructure (PKI).

3.2. Components for receiving

Signature validation – The calibration customer needs to ensure that the data included in the DCC is authenticated by the expected organization and has not been manipulated by third parties. This can be ensured by validating the digital signature in the DCC. In the PoC, the signature validation service was implemented as a part of the data transfer platform.

Human readable format – The DCCs need to be visualized to a human readable format to be used in manual processes. These can be, e.g., manual transfer of data to a calibration management system or a manual review of calibration results. In the project, a human readable format was developed using XSLT and JavaScript technologies. The human readable format was used to manually review and transfer calibration results to the calibration management system of the accredited calibration laboratory. The human readable format also included a user interface for validating the digital signature.

DCC CMS import – Utilizing the calibration data in calibration management systems (CMS) requires data extraction from the DCC XML document to the CMS database. In the PoC, a DCC data parser was developed to enable fully automated and error resistant data transfer process for the calibration customer. The DCC data parser was integrated to the customer's CMS (Beamex CMX) as a separate driver that enabled import from local data storage or DCC data transfer platform. After the data import, the calibration result could be reviewed and accepted according to current calibration processes. Finally, the calibration result data can be utilized in the CMS as part of instrument analytics and asset management processes.

3.3. General components in the data transfer platform

DCC sharing – The data transfer was implemented through a data transfer platform used by all the partners in the project. The data privacy of each organization was achieved though multitenancy. The data transit between organizations took place in the platform through transferring the DCCs between tenants. The platform user management also allowed to add user and visibility rights to specific DCCs for other organizations in the platform.

DCC storage – The long-term storage of DCCs was outside the scope of this PoC but the platform approach enables several options. If both the calibration provider and the calibration customer use the platform for long-term DCC storing, there is no need for unnecessary data replication as the same document can serve both parties. Either party can also take control of storing their own DCCs. In case both parties have local storages for their DCCs, the platform can be used only for data transfer and no data will be stored in the platform.

User management – The user management in the platform was based on Microsoft Azure Active Directory (AD). In the PoC, all the organizations used Microsoft AD for user management. The data transfer platform was developed to support single sign-on (SSO) through Microsoft AD. This allowed all organizations to use their existing authentication methods to authorize users to sign, transfer and manage DCCs in the data transfer platform. Microsoft AD integration also allows each organization to have full control of the users that can access to their organization's data. As the platform's user authentication is integrated as a part of organization's normal user authentication, the user rights to the platform can be added and removed automatically through normal employee onboarding and offboarding processes.

4. CONCLUSIONS

Interoperability between different information systems requires well standardized and universal data format. The universal DCC format has been designed to provide a framework for representing calibration data. It enables various ways to insert measurement data and recursive data structures which challenge the receiving end machine-readability. Need for interoperable machine-readability sets tight requirements not only to the DCC structure but also to the overall harmonization of the calibration certificates' content, including common and fixed vocabularies, glossaries, and semantics content. As use case specific needs and data formats can vary significantly, there needs to be a way to standardize the data in a more detail level.

To achieve use case level standardization, several good practice examples are currently being developed. The goal of the good practice examples is to standardize the representation of data, e.g., with a specific measurement quantity. As the PoC was executed before the first widely adopted good practice examples were published, there were challenges to achieve the adequate level of interoperability. In the first tests, only the universal DCC schema was used to validate the created DCCs. As a result, the CMS data import failed to read both DCCs created with the manual web form and the automated DCC creator. The finding highlights the importance of good practice examples and related good practice subschemas. The development of good practice subschemas should restrict the use of the universal DCC schema to the level where use case specific requirements are fulfilled, and interoperability ensured.

The development of good practice examples should be intensively coordinated between different working groups to avoid the risk of divergence. Also, the total number of different good practice examples should be minimized, and same data structures applied to as many different use cases as possible, to ease the implementation of the DCC.

In addition to the need of more precise standardization, also other technical findings were identified. The current version of the Digital SI (D-SI) does not support resolution for numerical values. For example, measurement result 1.00 will be saved as 1 in the XML which has implications, e.g., to uncertainty calculations. Also, calibration date or calibration due date of the reference instrument used in the calibration do not have a dedicated field in the DCC.

Wide reformation, like digital transformation, in a quite traditional calibration field will not happen in a second. And unfortunately, all stakeholders do not have resources to be involved in the development work. This leads to a situation where stakeholders do not have easy access to the latest development work, knowledge, and capabilities needed for DCC implementation. DCCs are currently developed mainly in few large European metrology institutions and some forerunner industrial companies. Support for the digital transformation and implementation of DCCs is needed. Especially end user needs in different industrial operations need to be considered, beginning from easy-to-use interfaces and support for DCC integration.

Our future work will include executing a new DCC PoC, cost saving analysis, streamlining calibration process, and search for new possibilities to exploit DCC data and business opportunities related to it (e.g., new services). The partners in the new PoC are VTT MIKES, Beamex, Lahti Precision, Orion, Vaisala, and Bayer. In this PoC, we will demonstrate mass and weighing instrument calibration cases. The PoC will examine a complete metrological traceability chain which begins from the SI and goes through NMI and accredited laboratory to the end user process without human intervention. More information on the reported PoC and the new PoC is available from the authors.

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