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Digital Calibration Certificates (DCC): Benefits and Challenges to overcome for implementation

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Abstract. The term Digital Calibration Certificate (DCC) has been increasingly prevalent in the metrology field, with national and international conferences where stakeholders discuss DCC. This article delves into the implications of integrating "D - digitalization" into "CC - calibration certificate," exploring the significant impact this concept brings to well-established practices. DCC represents a logical progression in the digitalization of metrology. Despite the existence of initial DCC implementations, it is essential to highlight the challenges that must be addressed before full-scale deployment. The discussion in the article focuses on raising questions about what DCC represents and the critical areas of focus before full deployment. The transition from paper-based calibration certificates to digital ones involves significant changes in the mindset of society to increase trustworthy in digital technologies. DCCs promise numerous benefits, including enhanced efficiency, traceability, and reliability in calibration processes, aligning with the broader trend of digital transformation in various industries. However, achieving these benefits requires a thorough understanding of the associated challenges. This article examines the aspects of DCCs, aiming to provide an overview of their benefits and the hurdles to be overcome for widespread acceptance.

1 Introduction

What exactly does the "D" in the abbreviation DCC stand for? While it is clear that it means "digital," it brings a revolution in how the CC (Calibration Certificate) is perceived. By adding "D," not only is the physical (paper) form removed, but it also introduces the integration of digital technologies with all their aspects. Digitalization in this context does not merely mean converting a document into a digital format but also encompasses comprehensive changes in the creation, handling, and sharing of calibration data. This step paves the way for better automation, traceability, and reliability in metrological processes. DCC can be considered a significant step in the digitalization of metrology, as it unambiguously demonstrates the benefits that digitalization can bring when applied to one of the fundamental pillars of metrology. If digitalization is effectively and positively implemented in the field of calibration, then its adoption in more advanced metrological processes will become more acceptable, even for a more conservative society. The current state of digitalization is characterized by aggressive development, advancing dynamically. In fields where calibrations are utilized, speed and efficiency are essential, leading to the development of various data standards, language models, big data processing, and an increasing integration of AI into processes. Therefore, it is crucial for DCC to evolve in a way that aligns with the needs of digitalization in metrology while preserving the mission of metrology, ensuring that digitalization technologies are not unintentionally overloaded at the expense of metrology itself. It is more important than ever to keep the essence of metrology as a priority.

2 Benefits of DCC in metrology

Summarizing the benefits of DCC in metrology is a simple task, as they can be observed in all processes that have been successfully automated and digitalized. However, it is certainly worth highlighting some of the significant benefits listed in Table 1.

Table 1. Typical significant benefits of DCC.

Benefit	Justification
Enhanced data access	It enables easy and fast access to information, accelerating various processes related to calibration.

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Machine-readable data	Enables optimization for automated processing, eliminating manual data entry and minimizing errors.
Elimination of paper	Transitioning to digital solutions reduces printing and distribution costs, contributing to environmental goals.
Integration support	DCC can be implemented into existing internal IT systems and support interoperability between different platforms.
Automation of metrological processes	Enables more efficient management of calibrations and management of the lifecycle of devices and instruments, improving planning and maintenance.
Support for digital twins	DCC can support digital twin attributes, improving process efficiency and safety across industries.
Improvement of traceability	Replacing paper-based processes with digital solutions enables quick retrieval and monitoring of calibration history.

It is also important to realize that DCC is not the only one pillar of digitalization in metrology so it must fit into the bigger concept of metrology digital for transformation. This means that the DCC concept must be designed to ensure interoperability, compatibility, modularity, and scalability while also establishing clear boundaries to ensure that metrology is always expressed clearly and comprehensibly. For this reason, several working groups focus on the development, implementation, and harmonization of DCC (see Chapter 5).

3 Trustworthiness in DCC

With the upcoming of digitalization and DCC, not only do benefits arise, but also associated challenges that require attention. It is essential to recognize all aspects related to the use of data in digital form, such as hardware and software requirements, cybersecurity, format, data handling, data integrity, data sharing, data copying, etc.

All of this leads to the questions: How can we trust data in the digital world? If we trust information on paper, what must be ensured to establish trust in digital data? If trustworthiness can be achieved in sectors such as banking and healthcare, then there must also be a way to achieve it in metrology. It is possible to identify three user groups (Fig. 1) that have an influence on the progress of DCC:

1. The first group consists of users who need and actively benefit from the "D" in DCC, as outlined in Table 1.
2. The second group includes users who are interested in the content of the CC and actively work with the data but often lack the resources (personnel and/or financial). They tend to wait for partial, ideally global, harmonization before adapting to the trend.
3. The third group consists of users who require CC for compliance reasons, such as audits, but do not practically use the data from CC.

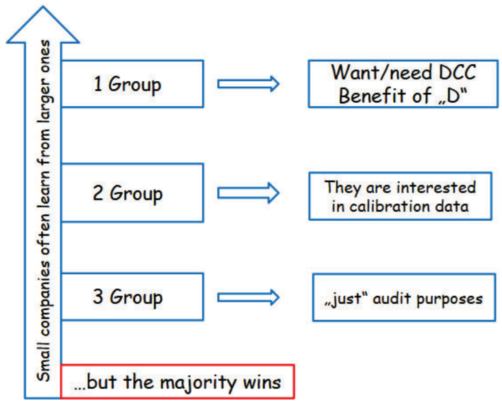

Fig. 1. Interpretation of user distribution influencing the progress of DCC deployment.

This classification reflects reality, and each country has a different distribution of these user groups. In general, small companies learn from large ones, but the principle of "the majority wins" often applies. One of the most common concerns of the second and third groups is the cost of implementing IT infrastructure, whether in terms of financial investment or resource capacity.

4 Challenges in DCC

The biggest challenge in DCC is achieving global harmonization. It is necessary to identify key factors, including:

- Each continent/country may have different expectations regarding DCC.
- The country's level of development/current state of digital/IT infrastructure.
- The society's stance on trustworthiness and acceptance of digital technologies.
- The time required for society to adapt to changes compared to established practices.
- Generation differences.

The aim of each country is to move society forward while avoiding unnecessary pressure for rapid changes. Some societies can adapt to changes more quickly, while others take more time. Therefore, building a digital infrastructure will likely be a long-term process, in some cases taking up to a decade. For this reason, adopting DCC in its advanced form right from the start will be challenging. However, a key driving factor is also generation change, as younger people tend to be more connected to digital technologies and have trust in them.

The available information [1] shows, that one of common concepts of DCC currently used is an embedded digital file within PDFA/3a [2].

Germany is undoubtedly the most progressive country in the field of DCC and its integration with digital infrastructure [3]. They are gradually progressing towards transforming their calibration processes to be based on digital documents and providing the necessary digital quality infrastructure to enable this [4]. Based on the content and attendance numbers of DCC conferences (1-4) [1], it is evident that almost everyone closely involved in this topic follows developments in Germany, including stakeholders that are already implementing DCC in the real field. However, there are still countries that lack the necessary IT/digital infrastructure to fully trust purely digital files. This gap can be attributed to varying levels of societal and technological maturity.

If we look at the technical aspects, the challenges include:

- Unified interpretation,
- Format,
- Compatibility,
- Development,
- Trustworthiness,
- Resources.

Regarding unified interpretation, one of the key advantages of the digital world is the ability to use a standardized, machine-interpretable language. The first step toward this is the creation of a unified digital vocabulary. One of the key working groups addressing this challenge is FMD-TG-MS (FORUM-MD ad hoc Task Group on Metrological Semantics) [15]. For a unified interpretation, it is crucial to maintain consistent semantics and properly structured ontology, which will eliminate barriers related to the use of different data formats such as XML, JSON, JSON-LD, and YAML. Additionally, digitalization constantly evolves, meaning that new formats may develop over time. This brings us to another major challenge - compatibility. While format compatibility is essential, it is also necessary to consider backward compatibility. Since DCCs already exist, future requirements must be designed to ensure that digital files created today can still be used 10-15 years from now. At present, we cannot fully predict what the state of the art will look like in the future, making long-term digital sustainability a critical consideration.

Some recalibration intervals are required every 1-2 years, which, from the perspective of the benefit of historical data traceability, represents only a minor data volume. As mentioned in the introduction, metrology must take precedence over technology. Currently, we can observe how certain IT solutions have become unsustainable within just a few years, while Calibration Certificates (CCs) remain valid. The expiration of calibration is not always strictly defined [5], making it crucial to ensure that DCC validity does not outlast the stability of IT solutions.

A special challenge is trustworthiness. One of the most frequently asked questions is: "How can I trust a digital file?" It is important to emphasize that in the field of software and IT security, it is extremely difficult to claim that something is 100% secure (Secure/Safety) [6]. However, it is possible to implement measures that support trustworthiness. Despite this, various software tools exist to ensure data integrity, such as encryption techniques, digital signatures, and other security mechanisms is generally known that the ingenuity in bypassing such security measures is constantly evolving and, in some cases, is even one step ahead.

Trustworthiness must be realized with precision—it is not enough to rely solely on high-quality software tools. A comprehensive quality management system must also be implemented including personnel training, processes for data and software verification, regular audits, etc. In summarizing these selected aspects, it is pertinent to note the use of resources.

It is natural to recognize that DCC may not be currently suitable for everyone. Implementing DCC brings additional demands on personnel, IT infrastructure, technology, and, of course, financial resources, which are often the decisive factor. However, we can observe a significant shift in the adoption of digital technologies. In relatively a short period, nearly every company has integrated IT into its operations, cloud services have become widely used [7], and the adoption of AI tools has grown rapidly in recent years [8]. From the perspective of the increasing use of digital services, the DCC concept is a logical step forward for metrology. Therefore, it is necessary to establish clear steps to facilitate the adoption of DCC. These steps have already been incorporated into the objectives and tasks of various working groups.

5 Harmonization and working groups focused on DCC

Currently, there are several working groups and projects dedicated to supporting the implementation of DCC. Their objectives include raising awareness about DCC within their fields, monitoring technological advancements, understanding user needs, and collaborating with other working groups to achieve a sufficient level of DCC harmonization that meets the requirements of all users.

Among the most significant international working groups are:

- FMD TG H-DCC/DRMC [9],
- EURAMET TC-IM 1448 [10],
- APMP TG H-DCC [11],
- SIM M4DT TF on DCC [12],
- Project CABUREK MDT-IC [13],

Each working group or project has its specific contribution, whether in technical development, implementation, or harmonization. Each group focuses on specific areas, and their outputs envisioned eventually can converge into an outcome (Fig. 2), which could be directed to FMD TG H-DCC/DRMC: Forum on Metrology and Digitalization ad hoc Task Group on Harmonizing Digital Calibration Certificate and Digital Reference Material Certificate with a global impact.

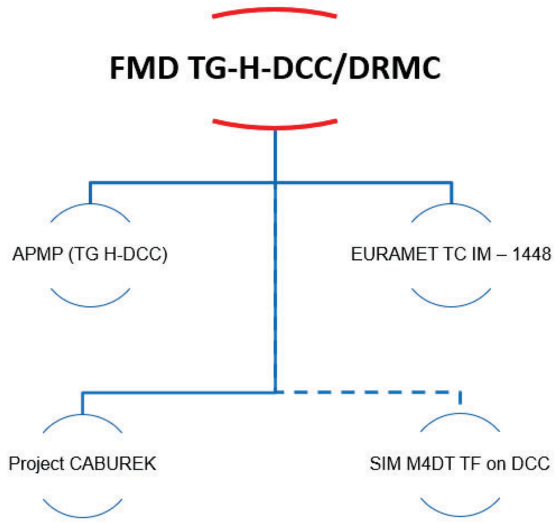

Fig. 2. Schematic representation of growing communication channels between significant working groups and projects focused on DCC.

This Task Group (TG) was established in March 2024 and is part of FMD (Forum on Metrology and Digitalization) [14], whose primary mission is to advise the CIPM (International Committee for Weights and Measures) on the SI Digital Framework and the wider implications of the global digital transformation for metrology and for the international Quality Infrastructure. From the perspective of interactions between TGs and WGs within FMD, in relation to the significance of DCC and DRMC, the following schematic representation can be observed in Fig. 3.

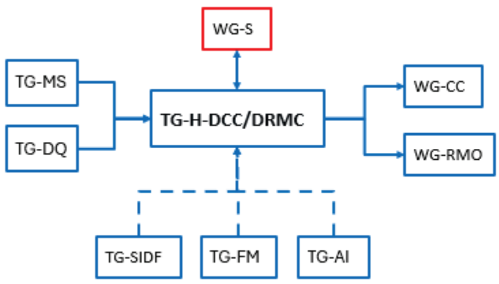

Fig. 3. WGs and TGs interaction in FMD from the perspective of TG-H-DCC/DRMC. (TG-MS: Task Group on Metrological Semantics, TG-DQ: Task Group on Data Quality in Metrology, TG-FM: Task Group on FAIR for Metrology, TG-SIDF: Task Group on SI-digital Framework, TG-AI: Task Group on Secure and Trustworthy AI, FMD-WG-CC: Working Group on coordination between Consultative Committees, WG-RMO: Working Group on coordination between Regional Metrology Organizations, WG-S: Working Group on Strategy.)

From the schematic representation, it is clear that TG-H-DCC/DRMC is not independent and it relies on inputs from other TGs and provides outputs to WGs. Therefore, in addition to the harmonization of DCC/DRMC, this TG also plays a role in the digitalization of metrology as a whole. The establishment of this TG is a significant step toward the implementation of DCC, as it represents a global collaboration across continents. The strategy of this TG is defined through goals and tasks (Fig. 4) to achieve global harmonization for DCC and DRMC.

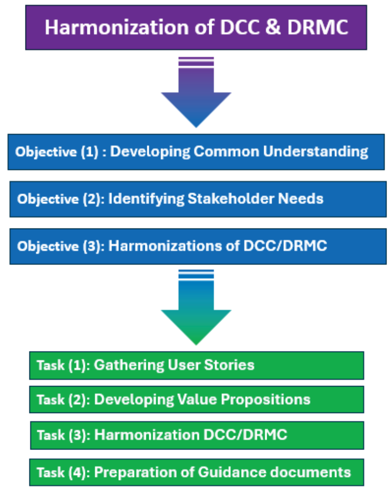

Fig. 4. List of FMD TG-H-DCC/DRMC objectives and tasks.

If we take a closer look at the goals and tasks, the purpose is not to start from scratch. It is essential to summarize what already exists, what is actively used, and continuously update this list. This approach allows for a better identification of the (already extensive) benefits and, more importantly, the needs of stakeholders. This can be achieved through workshops and various conferences. Subsequently, it is possible to consider what will need to be harmonized and what the level of harmonization or its boundaries will be. There are already enough identified assets that can serve as a foundation for further development.

6 The Future of DCC in Metrology

DCC is the future of metrology because we live in a digital age. Metrology is an integral part of this era—just consider the number of sensors surrounding us daily, how many of them are critical, how they influence the quality of our lives, and the key role that calibration plays in ensuring their reliability. The imagination that a single person or a small team is responsible for managing the calibrations of 5,000 devices may seem archaic in today's digital world, but it remains often a reality. The implementation of DCC will likely become as indispensable as the use of smartphones or PCs. Furthermore, new global challenges are emerging where DCC will be essential, including improved product traceability [16 - DPP], utilization in Sensor Networks [17, 18], or training of AI models [8]. Harmonization of DCC is, therefore, more than just desirable, it represents a crucial milestone for the successful digital transformation of metrology.

7 Conclusion

The article points out that DCC brings many benefits as well as challenges that need to be faced. Even though the technical term and the general concept of the DCC has been around for almost a decade, we are still at the beginning. However, with the advancement and development of new technologies, it is only a matter of time before DCC is widely deployed. Before that happens, there is certain “homework” that must be completed to ensure that DCC deployment will be effective and with a vision for the future. DCC is a key factor in the future of digital metrology, but given the enormous number of digital technologies surrounding us, its role is crucial not only for industry but also for society as a whole. As already mentioned in the article, when implementing DCC, it is essential to ensure that new digital technologies do not weaken the role of metrology itself. Most innovations depend on metrology, and if metrology were to be compromised in favor of new technologies, it is highly probable that these very technologies would ultimately be doomed to failure.

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